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A MANAGEMENT PLANNING AND CONTROL SYSTEM FOR NAVAL TEST AND EVALUATION PROJECTS

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A MANAGEMENT PLANNING AND
CONTROL SYSTEM
FOR NAVAL TEST AND EVALUATION
PROJECTS

By

James R. Talbot, Jr.

Bachelor of Arts

University of Virginia, 1953

A Thesis Submitted to the School of Government,
Business and International Affairs of the George
Washington University in Partial Fulfillment
of the Requirements for the Degree of
Master of Business Administration

May 21, 1964

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PREFACE

In 1961, as a comptroller, I participated in an attempt at systematic analysis of planning and scheduling problems in test and evaluation project management at the U. S. Naval Air Turbine Test Station in Trenton, N. J. That analysis sought to identify the common features in projects assigned by the Bureau of Naval Weapons, and to develop data collection for management and supervisory use within the constraints of the existing mechanized accounting system. The goal of the analysis was the regularizing of project management along conventional level of effort lines to accelerate project completions and increase efficiency of resource use.

This early effort aroused my interest in an exploration of some of the new techniques of project management, even though they were primarily computer-oriented and thus not apparently directly useful at NATTS. This interest became of immediate practical concern upon my assignment to duty under instruction at the George Washington University, where a thesis was to be required.

The excitement in the Navy over the management improvement possibilities in the rapidly developing PERT systems led me to do some basic reading in the subject. It seemed that some unsophisticated adaptations of PERT concepts should be applicable to the planning and perhaps the control of test and evaluation projects. It is in pursuit of this idea that this research paper developed.

INTRODUCTION

During World War II business and government experienced an unprecedented growth in both size and complexity. Geared to the needs of total war, both sectors of the American economy employed large numbers of scientists and mathematicians. While these men were primarily engaged in pushing outward the boundaries of technology in the name of the war effort, they unavoidably became involved in the operational and managerial problems of big business and bigger government. Under the influence of these men, or of their ways of attacking problems, managerial problems were, and since then have been, subjected systematically to new techniques in the quest for sounder and more rapid solutions. These new management techniques are largely quantitative and mathematical in nature.[1] Successively wider areas of what had previously been considered qualitative matters not subject to measurement have been quantified, or at least treated for decision-making purposes as though they were quantifiable. These "scientific" methods of attacking managerial problems may be classed approximately under the heading "scientific management".

As operations, private or public, become larger and more complex, the need for data for planning and control purposes - for management purposes - grows. In modern industrial society the volume of data required is expanding, and the timeliness of the data becomes increasingly important. In the last fifteen years, and more especially in the last ten, the electronic computer

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[1] H. A. Simon, The New Science of Management Decision (New York: Harper & Bros., 1960), p. 14.

has become a major implement in the processing of data. Electronic computers are capable of speed and accuracy which is a quantum jump over previous means of data processing. Not only can information be had more rapidly and accurately, but more data can be processed to produce the required information within the required time. While the computer is a valuable tool to the "scientific" management techniques, its rapidly growing capabilities have in turn accelerated the development of these new approaches to management problem-solving and decision-making.[2]

One family or group of management planning and control techniques is based on network analysis and on automatic processing of control data and of action alternatives. These techniques include the Critical Path Method (CPM), Least Cost Estimating and Scheduling (LESS), Program Evaluation Procedure (PEP) and Program Evaluation Review Technique (PERT). They all begin with the development of a graphic portrayal of the concurrent and sequential relationships among the parts or steps in the completion of a project. Then time, cost, or performance values, or a combination of these, are assigned to each of the parts or part-relationships in the network. From this weighted or valued network the controlling sequence of parts - the critical path - can be identified. Further, by shifting resources from one path to another, time, cost or performance characteristics of the project can be altered.

The newest of these techniques is PERT. PERT was developed as a management tool for the POLARIS weapons system development project.[3] Like many of the kinds of projects for which the network techniques were

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[2] E. C. Bursk and J. R. Chapman (eds.), New Decision-making Tools for Management (Cambridge, Mass.: Harvard University Press, 1963), p. viii.

[3] Ibid. p.x.

developed, POLARIS was a very large, very complex project involving research, development, test, evaluation, and production. The number of parts or operations in the project was enormous. Thus the development, analysis, and maintenance of the network in both planning and controlling dictated the use of automatic data processing.[4] The POLARIS program provided a major strategic nuclear weapon capability to the U. S. Navy. The project was richly funded, especially staffed, and highly publicized. These circumstances undoubtedly mitigated in favor of the PERT technique, and accelerated its development. Nevertheless, the success of the POLARIS effort demonstrated the soundness of the PERT technique, at least under those conditions. As a result almost every major government program in defense and space is using the technique,[5] and PERT-type reporting to the services is required of private industry in major development contracts.[6]

Network systems - PERT-type systems - involve expensive data gathering, processing, and reporting effort, and expensive computing equipment. Estimates of the cost of such systems run as high as double the cost of "previous systems".[7] It is for this reason, at least in part, that network systems have seen their major development in large, computer-equipped projects. Yet the essential characteristics of network systems is not hardware or data volume or large project cost. Rather, the essentials seem to be a systematic and analytical approach to the project in hand, assisted

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[4] Ibid. p. 96.

[5] Ibid.

[6] William Hunter, Industrial Engineering Consultant, Navy Management Office, "The PERT System", lecture to Navy Graduate Financial Management Program, 5 December 1963.

[7] J. Bolen and R. LeDuc, IBM Space Guidance Center, "PERT/COST Case Study", lecture to Navy Graduate Financial Management Program, 22 January 1964.

by graphical display, commenced in advance of work commencement. If this is so, some of the advantages of these systems should be available to any project or job of work regardless of the size of the budget or the degree of automation available in the data processing function. Further, though these systems have been developed primarily in one-of-a-kind programs to help handle the uncertainties involved in the absence of standard cost and time data, they should be useful in projects with some degree of routinization, especially where standards are not available or not well developed.

The Navy has a variety of test stations and facilities performing test and evaluation work for the Bureaus of Naval Weapons and Ships. The Naval Ordnance Test Station at China Lake performs tests and evaluations of underwater ordnance and of guided missiles. The Naval Air Test Facility, Patuxent, Md., works for the Bureau of Naval Weapons on aircraft and aircraft equipment and runs aircraft service acceptance tests for the Board of Inspection and Survey. The Operational Test and Evaluation Force and the Torpedo Station at Newport, R. I., perform test and evaluation work for both bureaus. The Naval Air Turbine Test Station, Trenton, N. J.: Naval Air Development Center, Johnsville, Pa.,; and Naval Air Test Facility, Lakehurst, N.J., do test and evaluation work in aircraft, aircraft systems and components, turbo-jet engines, catapults, and so on. While the trend at these activities, as in the Department of Defense as a whole, is toward the automation of the data processing function, the rate of automation is a function of such variables as project size or importance, activity size, defense budget size, and the like. In the interim, the benefits of advances in management techniques should be extended in advance of hardware funding and personnel ceiling allocations. To state this raises the question, can the techniques of network systems be adapted to non-automated naval test and

evaluation effort?

The purpose of this research paper has been to seek an answer to that question. Specifically, what has been investigated is the applicability of network techniques to management planning and control of test and evaluation projects. Emphasis was placed on the managerial rather than the supervisory aspects of the question. The need for effective planning and control has been succinctly stated in the PERT Coordinating Group's Guide for Management Use where it was noted that twelve major weapons programs averaged a cost overrun of 3.2 times original estimate and an average time span of 1.36 times original target.[8] While these two numbers must be taken together, since it is very likely that some time was bought with money, either figure is significant in itself. They represent areas of significant potential management improvement, for which the PERT family of systems was developed. The extension and adaptation of these techniques over wider areas of management effort should be fruitful.

Network systems are in a state of continuing development and refinement. Much of the writing in the field rapidly becomes obsolete. Therefore library research was conducted with emphasis on recent materials and on concepts. These materials were supplemented with information sought from lecturers in management to the 1964 Navy Graduate Financial Management Program at the George Washington University. Finally, interviews relating to management problems in test and evaluation were conducted at the U. S. Naval Air Turbine Test Station, Trenton, N. J. (NATTS).

The test and evaluation work at NATTS Trenton was taken as representative of the repetitive and non-repetitive characteristics of naval test

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[8] PERT Coordinating Group, PERT Guide for Management Use, (Washington, D. C., June, 1963), p. iii.

and evaluation, and investigation of network systems was conducted against that background. Where example and illustration is required in this paper a hypothetical jet engine test and evaluation project will be used. It is emphasized, however, that the management system developed in this paper is not an attempt to resolve management problems at NATTS Trenton, or to devise a mechanism for conduct of aircraft engine testint at NATTS or the Jet Propulsion Laboratory or any other specific application. Rather, the intent is to develop a general approach to the management of test and evaluation effort on a project basis in the absence of a business-type computer installation or in the circumstances where the project is "too small" to warrant the overhead costs of "putting it on the computer", and to suggest therewith the basis on which the desirability of a new technique should be judged.

CHAPTER I

NETWORK SYSTEMS[1]

A system is an orderly combination or arrangement of parts, or an orderly process. A network is a system of interlacing lines, tracks or channels. In network systems, then, the planning and control of a project or job of work is accomplished through the identification and analysis of an interlacing arrangement of the parts of a project. Network systems of management planning and control have been developed to deal more efficiently than previous systems with projects that

1. Are new or untried, or infrequently repeated,
2. Are large and complex,
3. May be separated into well-defined parts or jobs,
4. Have parts which, in the proper sequence, may be started and completed independently of each other,
5. Must be performed in technological sequence.

If a single characteristic can be sorted out to differentiate network systems from previous systems it is that they can visually represent the interconnections and interdependencies, the coordinate functions and precedent relationships among the parts of the project. Network systems have been used on a wide variety of projects having the characteristics

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[1] This description is a synthesis of the descriptions in G. N. Stilian *et. al.*, *PERT: A New Management Planning and Control Technique* (New York: American Management Association, 1962), and F. K. Levy, G. L. Thompson, and J. D. Wiest, "The ABCs of the Critical Path Method", *Harvard Business Review*, XXI, No. 5 (September-October 1963) 98-108.

listed above. The significance of the interrelationship feature can be seen in such projects as

1. The POLARIS missile/submarine weapons system project,
2. The construction of a building,
3. The installation of a new computer,
4. The launching of a play.

The basic technique of network systems involves the development of a model (network) of the project, an evaluation and adjustment of the model to provide assurance that the operating plan derived from it incorporates all requirements to reach the objective, and the development of controls to monitor the operation the network represents. The network model is a graphic plan of action, a roadmap visually presenting the route to the goal.

To develop the network, each of the jobs necessary to complete the project must be identified by a descriptive title. Commonly, each job is then assigned an identifying number. Then the jobs are arranged in technological order, that is, in such an order that no item on the list precedes items which must be accomplished before it can be commenced.

Next the network is drawn. Graphic techniques vary at this stage. One method is to represent each job by a circle, then to show the sequence relationship between jobs with arrows. Another method represents "events" by circles, with the connecting arrows representing the jobs. The latter method may be more useful in that it allows room for more information on the graph. At this point the graph represents a number of arrow paths from the first job to the last. Conventionally, pseudo-jobs called Start and Finish are employed for clarity, and the arrow paths then show routes from the beginning to the end of the project.

Then the network is weighted. Each job is assigned an estimate of

elapsed time, or cost, or both. The sum of values along each arrow-path in the network, then, is the total elapsed time or total cost along that path from Start to Finish. If, then, calendar dates are assigned along each path to conform to the elapsed time estimates, a schedule of each job and of the whole project results. The calendar time assignments may be applied from Start to Finish to estimate the completion date, or from Finish backward to Start to estimate when a project must be commenced in order to complete it by a chosen or directed date.

It can be seen from this description that one arrow-path will be "longer", have a greater amount of elapsed time, than any other path. This path is the path that controls the duration, and completion time, of the entire project, and is referred to as the "critical path". Any delay in the jobs on this path will delay final completion of the project. It may occur that two arrow-paths have the same lapsed-time estimate which is greater than all the others, in which case both paths would be critical paths. It also may occur that as work progresses on the project and performance deviates from estimates, some other path would supplant the originally estimated longest path as the new critical path.

The two general classes of network systems may be distinguished by their method of dealing with time. The Critical Path Method is "deterministic" in that it requires a single estimate of time for job completion under "normal" conditions. This time is derived in terms of costs. That is, under the optimum use of time, money, manpower, and method, a given job will be performed at a minimum cost. The elapsed time related to that cost is normal time. A less than optimum employment of resources will use more than "normal" time, but will also increase costs because of the fixed costs of being in business. In the other direction, a job can be expedited up to

a minimum possible time, called the "crash" time. The associated "crash" cost is more than proportionately higher. Any level of effort can be planned, but in any event, one determined time and cost is employed in the method.

The PERT method lacks the cost--time function of CPM but has the advantage of combining planning and scheduling in a time estimate which includes a consideration of the uncertainty of each job in the project. Each job is estimated by the person most familiar with the kind of work involved. But instead of one time estimate being prepared, three are: an optimistic estimate, a most likely, and a pessimistic estimate. The most likely or normal time is that time which would occur most often if the job were performed several times under similar conditions. The pessimistic time is the maximum time a project would take under the most adverse conditions not including catastrophes. The optimistic time is the minimum time a job will take, as a result of unusual good luck. These times are averaged, giving a weight of one to the extreme estimates and of four to the most likely and the result is the "expected" time. This expected time has a 50% chance of being achieved. The probability of achieving a scheduled project completion date can be computed from the sums of the scheduled times and the standard deviations of all the jobs that make up the project.[2] PERT, then, is "probabilistic" in that it includes a means of dealing with the uncertainties of new or one-time projects such as the POLARIS development project. This is in contrast to the deterministic CPM system which has been used in

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[2] For a concise description of the mathematics of the expected time estimate see E. C. Bursk & J. F. Chapman, *New Decision Making Tools For Management* (Cambridge, Mass: Harvard University Press, 1963), 114-118. An analysis of these computations is in *PERT Summary Report Phase I* (Washington, D. C.: Special Projects Office, Bureau of Naval Weapons, July, 1958).

projects, where the individual jobs involved are backed by considerable previous experience in method, manning, and cost.

There are differences in mechanical details and terminology among all of the network methods. None of them are of major importance but they do require the person seeking knowledge of the systems to wade through a variety of glossaries and descriptions of diagramming sequences that in the end turn out to be essentially the same. For example, one approach to CPM requires the listing of each job in a project together with the time and resource estimates before beginning network diagramming. Most PERT descriptions, on the other hand, either ignore time estimates until after the network is drawn or specifically state that estimates should not be made at the job tabulation stage. As is the case in any new and growing field, there has not yet developed a real consensus in terminology or mechanics. Therefore, what has been selected for this paper should not be regarded as the most common or most popular or best terminology and technique, but a selection from among many variations on the same theme. The following general definitions are approximately as used in the PERT Coordinating Group's PERT Guide.[3] "PERT" will be used in a generic sense to mean networking analysis.

A work breakdown structure is a graphic representation of the component parts or jobs of a project. It defines in successively greater detail how the various end items of work are related to the overall project. The work breakdown structure is the basis for constructing the project network. The successive subdivision of work is continued to the point where the item subdivisions become useful for management planning and control.

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[3] PERT Guide for Management Use.

The item subdivisions are then broken down into work packages. These are units of work required to produce a specific item, such as a piece of hardware, a set of drawings, a report, or a service, which is the responsibility of one operating unit within the organization working on the project. Work packages consist of one or more activities. Activities are parts of a work package which have been separately identified to facilitate control of effort. In some instances one work package is treated as one activity.

A network is a graphic description of the planned sequence of activities leading to the completion of the project. It shows the relationships and constraints of the activities comprising the project.

A network activity is represented by an arrow. Performance of the work in an activity leads to an identifiable point in time called an event. An event is the basis for monitoring the activities in a network, and can often partly identify the activity: "Complete Activity 7". An event may represent the beginning or completion of a significant phase of the whole project. Events are sometimes referred to as milestones. Events are represented by circles.

Elapsed time (te) estimates are assigned to each activity in a network, usually in weeks. Either a single estimate or a range of estimates may be used, depending on the nature of the activity. The more uncertainty involved the more desirable the range-of-estimates. If an activity involves well-known work with experienced personnel, a single estimate would suffice. For example, at the IBM Space Center much of the work is research and development which presses the limits of the state of the art in space technology. Therefore, the computer program for networking is constructed for the three estimate method. But where an activity or work package has become routine, and one estimate will therefore approximate the probability

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of three, it is merely entered three times.[4] When all activities have been estimated, the network may then be converted to calendar time.

The elapsed time estimate (te) of all activities are accumulated through the various network paths. The earliest expected completion date (TE) is thus developed for each event. The earliest expected date of the last event is the expected date (TE) of the project.

Sometimes a project assignment includes a desired or required completion date. This is referred to as a directed completion date (TD). Or a predetermined target date may be established within the organization. In either case, by working backward through the network a latest allowable date (TL) can be established for each event which will permit completion of the last event - and therefore the project - by the project's latest allowable date (TL).

The longest time path through the network has been called the critical path. All other paths will have a different elapsed time than the critical path. This difference is called slack. The amount of slack is computed by subtracting the expected date from the latest allowable date. If TL minus TE is positive - if positive slack exists - then there is time to spare. That is, the event or network path under consideration can be delayed or allowed to slip by the amount of positive slack without delaying the overall project. If TL is equal to TE, no slack exists. This is referred to as zero slack, and is the case for each event along the critical path. If the latest allowable date is earlier than the expected date for an event - if TL minus TE is negative - then negative slack exists. Negative slack indicates the need to revise the initial planning.

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[4] Bolen and LeDuc. "PERT/COST Case Study" lecture.

The foregoing definitions deal with the planning phase of a project. Some additional terms pertinent to scheduling will have to be introduced so that controls can be dealt with, but these shall be left until they are needed.

CHAPTER II

TEST AND EVALUATION PROJECTS: AN EXAMPLE

Test and evaluation can be simply described as getting the answer to the question, "Does it perform as it is supposed to perform?" Naval activities such as those mentioned previously are primarily, though not exclusively, in the test and evaluation business. Items of military hardware which are under development or are about to enter production must be tested and the results evaluated for acceptance. Equipment or components in use may suffer unexplained failures. Test and evaluation activities will be required to find the causes of failure and a means of preventing future failure. "Off-the-shelf" civilian hardware may be considered for military use and would have to be tested and evaluated against the requirements of military service.[1]

Most test and evaluation projects are assigned to test and evaluation activities by directive from their management bureaus, though some are internally generated. Test and evaluation projects have to some degree the uniqueness of research and development projects, especially when they involve finding a "fix" for a defect in a piece of equipment which has developed in service. Indeed, some projects assigned to test and evaluation activities are for practical purposes pure research and development.[2]

Although test and evaluation work may exhibit a large degree of

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[1] U. S. Naval Air Turbine Test Station, Trenton, N. J. Personal interviews with top management, 21-23 December 1963.

[2] *Ibid.* Interview with the Director, Aeronautical Turbine Laboratory.

"one-of-a-kindness", it has also, to a significant degree, the repetitive characteristics of job-shop production. This results from the fact that the mission and tasks of any one test and evaluation activity reduce its field of work to a relatively narrow range of equipment and components. And within each class or category of items under the cognizance of one activity the projects assigned tend to repeat themselves in general outline and technique if not in detail.[3]

To illustrate in general terms the nature of a test and evaluation project and to provide a case for use in a hypothetical planning and control system, a dummy project will be described. It will contain many of the common features of the projects assigned to NATTS Trenton. To provide an exercise for a broader range of the devices in the PERT time technique, it will include more requirements than is usually found in one NATTS engine project. Except for this artificiality it will be representative of jet engine test and evaluation projects at that activity and except that the kind of equipment is different, will exhibit many of the general characteristics of test and evaluation projects.

A typical jet engine test and evaluation project for the J-1 engine might require evironmental testing to determine that the engine will meet the manufacturer's speed and altitude guarantees, meet performance specifications for high and low temperature operating conditions, and will be able to ingest a specified weight of water without failure. To conduct these tests the activity has two instrumented test cells in which engines can be operated under controlled conditions. The cells have supporting facilities to provide inlet air at controlled temperature and velocity and one cell has exhaust facilities to be able to evacuate the cell to controlled

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[3] *Ibid.* Interview with the Planning Officer.

altitude equivalent. A considerable inventory of sensors is available to instrument the engines under test, and shop facilities are provided to fabricate test stands on which to mount the engines, harnesses on which to mount leads to the instrumentation mounted on the engines, and rigs to supply controllable quantities of water to the area around the engine inlet. Drafting and engineering services are available as well as scientific data reduction facilities. For simplicity it will be assumed that the test project will not require modification of the buildings or installed equipment. In reality this is not an infrequent occurrence, and a determination must be made as to whether the modifications enhance the capability of the physical plant and thus require authorization under the military construction program or will be of use only for the project at hand.[4] In the latter case, some additional detail would have to be described below.

The activity is funded on a level-of-effort basis, and project directives from the management bureau prescribe a desired degree of priority in relation to the other projects on hand. Thus a normal priority project can be delayed by another project using the facilities of the activity.[5] The final product of a test and evaluation project is a formal report. Information developed as the project proceeds is provided, where it is meaningful, to the management bureau through interim reports.

The test and evaluation project for the J-1 engine, then, consists of three parts:

1. Altitude Guarantees.

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[4] Ibid. Interview with the Controller.

[5] Ibid. Interview with the Controller. Level-of-effort means substantially the same budget as last year with substantially the same personnel ceiling. Some activities are now operated on a modified industrial fund basis.

2. High/Low Temperature Qualification.

3. Water Ingestion Tests.

The first part requires the services of the altitude test cell, the latter two can be conducted in the sea level cell to free the altitude facility for other projects. There are distinct phases in the work required for each of these three parts, including:

1. The engineering work required to prepare the detailed test outline, the design and drafting work required to provide the hardware and instrumentation rigs for the engine in each cell, and computer programming for reduction of the data produced by the testing.

2. The installation work involving hardware fabrication, instrumentation, and engine preparation necessary to have the engine in a cell and ready to operate.

3. The testing conducted to obtain the data from which the project engineers will make their evaluation and write their report.

4. The removal work involved in removing the engine and hardware from the test cell, clean-up and inspection of the engine, instrumentation and test cell facilities.

5. The engineering and related work involved in data reduction, analysis, and interim and final report writing and "publication".

Each of these phases must be substantially complete before the next one can commence, though at some risk of rework, work in the installation phase can be commenced as work in the preliminary engineering phase is completed. At the other end, data reduction can to some degree run concurrently with testing depending upon the capabilities of the scientific data processing installation. The five phases of work listed above can be subdivided further into identifiable areas of responsibility. An organization

structure representative of this responsibility is shown in Figure 1. In the preliminary engineering phase the areas of responsibility or areas of individual control are:

1. Preparation of a test outline specifying test instructions and data to be taken.

2. Preparation of instrumentation specifications and drawings to conform to the data points described in the test outline.

3. Engine installation design and drafting work.

4. Programming the scientific data processing facility based on the test outline, and checking and debugging the program.

In the installation phase the work subdivides into:

1. Fabrication or modification of engine support hardware, required ducts, diffusers and the like.

2. Fabrication of assemblies for meters, probes, leads, etc., for instrumenting the engine.

3. Preparation of the engine including mounting accessories, dissassembly and reassembly incident to instrumentation, and maintenance and repairs incident to test operations.

4. Installation of the engine and supporting hardware in the test cell, and alignment work.

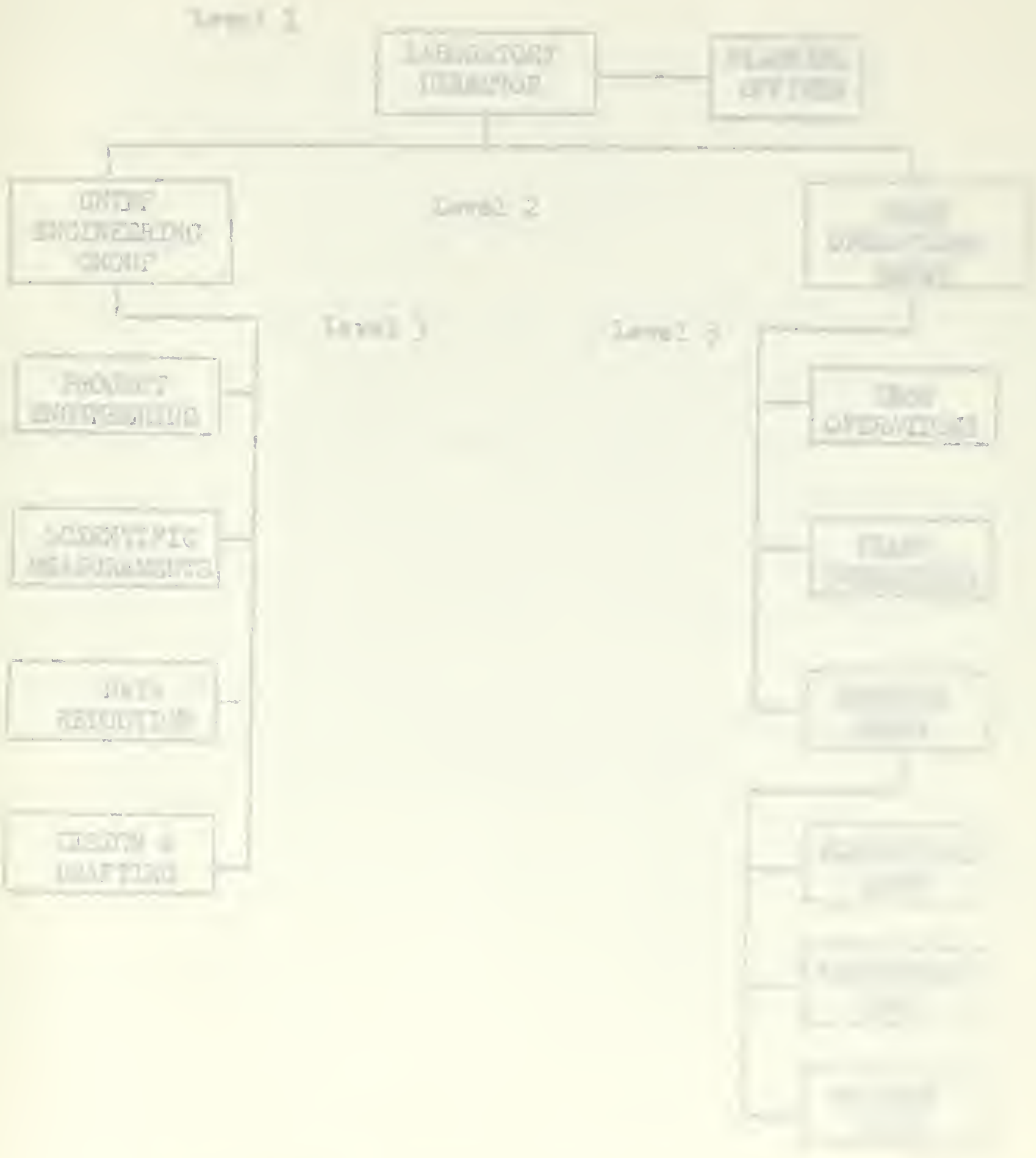
5. Instrumentation installation, including hookup to recorders, and checkout.

The test phase includes operation of the engine from the first pre-flight checks to the end of the final preservation run, including operation of all supporting equipment, data acquisition and recording equipment, and, as a matter of practicality, minor fabrication and

ORGANIZATION CHART

FOR

TEST AND EVALUATION PROJECTS



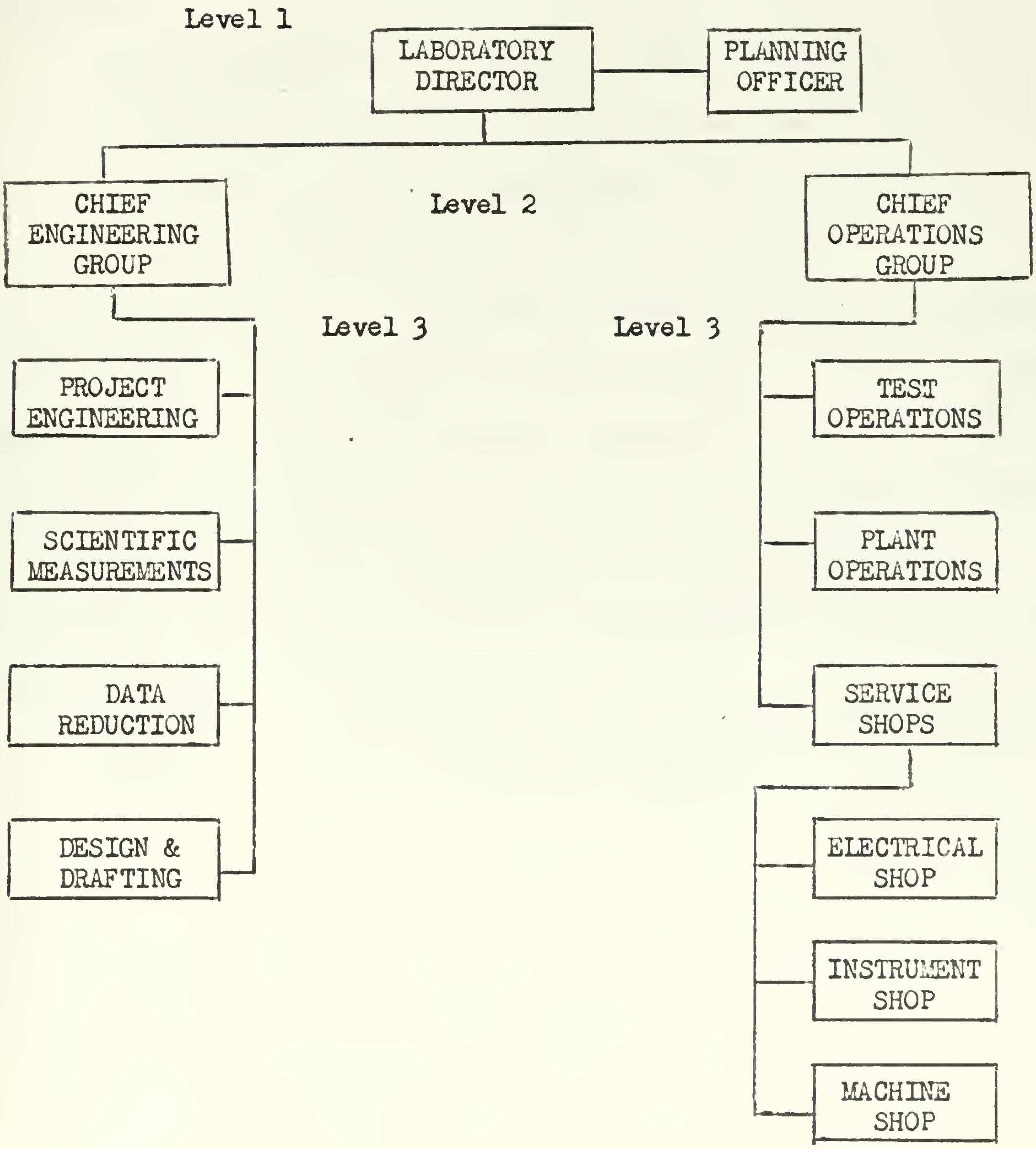
Representative organization structure illustrating the functional breakdown of the Aeronautical Turbine Laboratory, Naval Air Turbine Test Station, Trenton, N. J.

Figure 3

ORGANIZATION CHART

FOR

TEST AND EVALUATION PROJECTS



Representative organization structure illustrated by functional breakdown of the Aeronautical Turbine Laboratory, Naval Air Turbine Test Station, Trenton, N. J.

Figure 1.

installation work incident to minor failures and minor test program revisions.

The removal phase covers post-test equipment calibration, engine removal and hardware teardown, and post-test inspection and repackaging of the engine.

The post-test engineering phase is subdivided into:

1. Reduction, automatic or manual, of test data.
2. Analysis and report preparation.
3. Report publication.

These breakdowns of the effort required to conduct a test and evaluation of a jet engine can be used for each of the objectives enumerated in the initial three-part breakdown. They have been found adequate with additional control subdivisions for such tests as performance envelope determination, component performance evaluation, transient-state performance determination, and so on.[6] The foregoing listings are more easily visualized in Figure 2.

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[6] Ibid. Interview with the Planning Officer.

AIRCRAFT ENGINE ENVIRONMENTAL TEST PROJECT

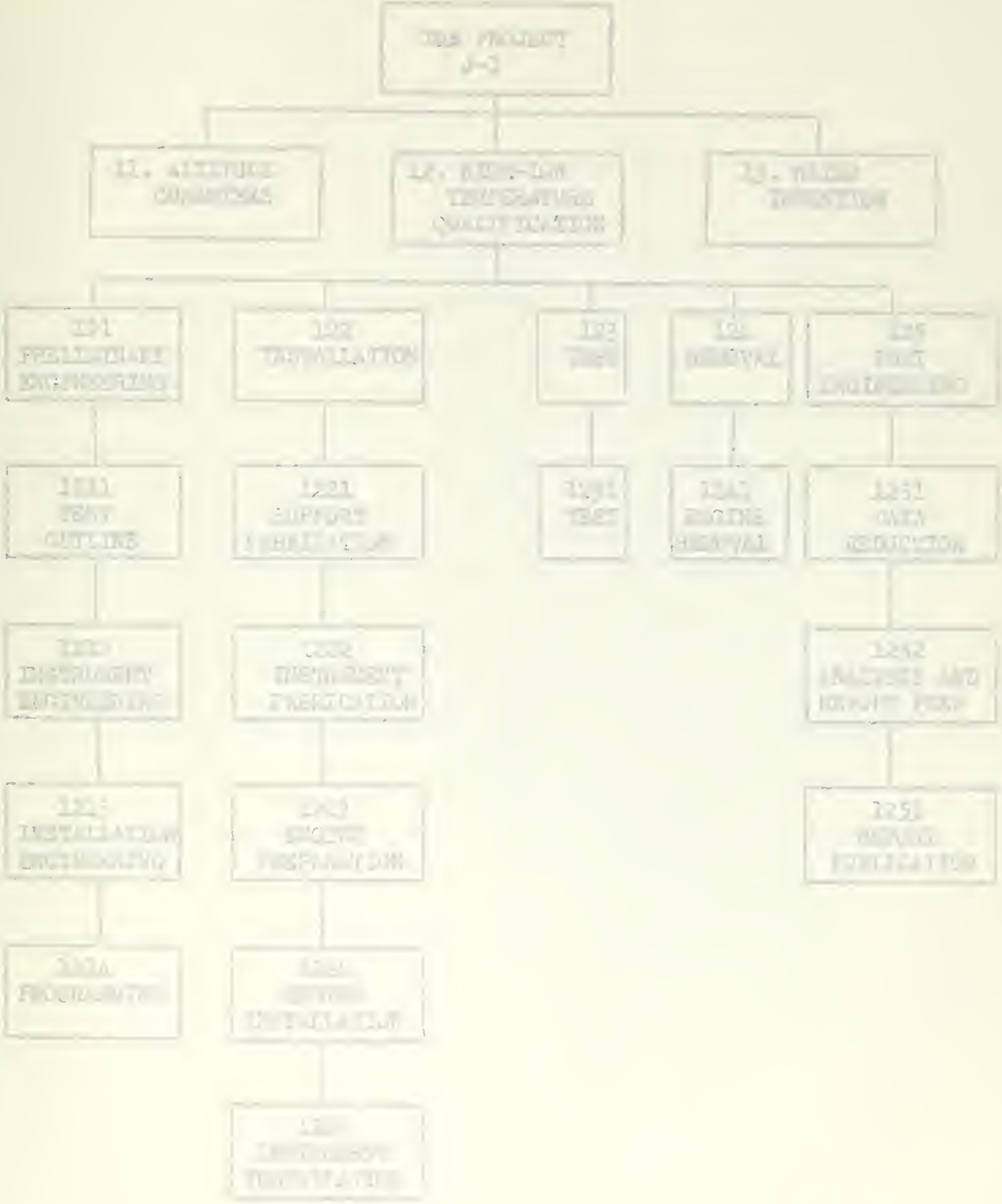

Figure 2

AIRCRAFT ENGINE ENVIRONMENTAL TEST PROJECT

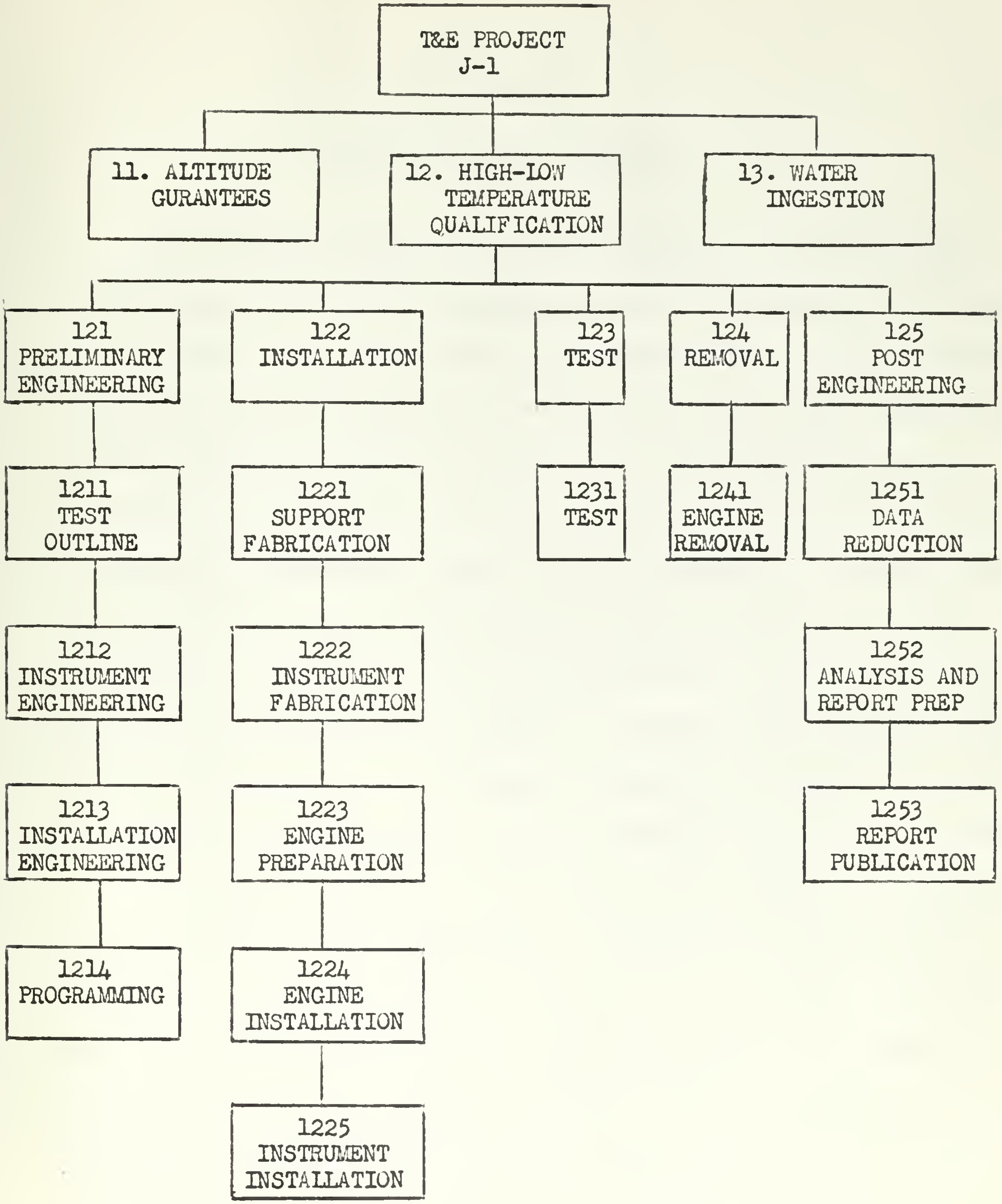

Figure 2.

CHAPTER III

THE PERT NETWORK: PLANNING

The successive subdivisions of the example test and evaluation project are logical reductions of the work required to meet the objectives of the project, and relate to the organizational structure established to perform the work (see Figure 1). Thus the work does in fact subdivide into a Work Breakdown Structure - a framework for defining the work to be accomplished, constructing a network plan, and summarizing the status of a project for progressively higher levels of management.[1] Further, the lowest level of the breakdown structure, while not the most detailed description of the work as it will actually have to be performed, is in each case the work required to complete a specific job or process. That is, it is a work package subdivision of the project.[2] Figure 2 is partly recast in the form of a work breakdown structure in Figure 3 to illustrate.

With the work clearly defined in the work packages, the project can now be translated into a PERT network. To facilitate networking, the activities are tabulated with their related events in Table 1, and each activity and event are assigned an identifying symbol. The network in Figure 4 is a flow diagram of the activities and events which have been determined to be necessary to reach the project objective. The diagram

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[1] PERT Guide for Management Use, p. D.4.

[2] Ibid.

WORK BREAKDOWN STRUCTURE

TO THE WORK PACKAGE

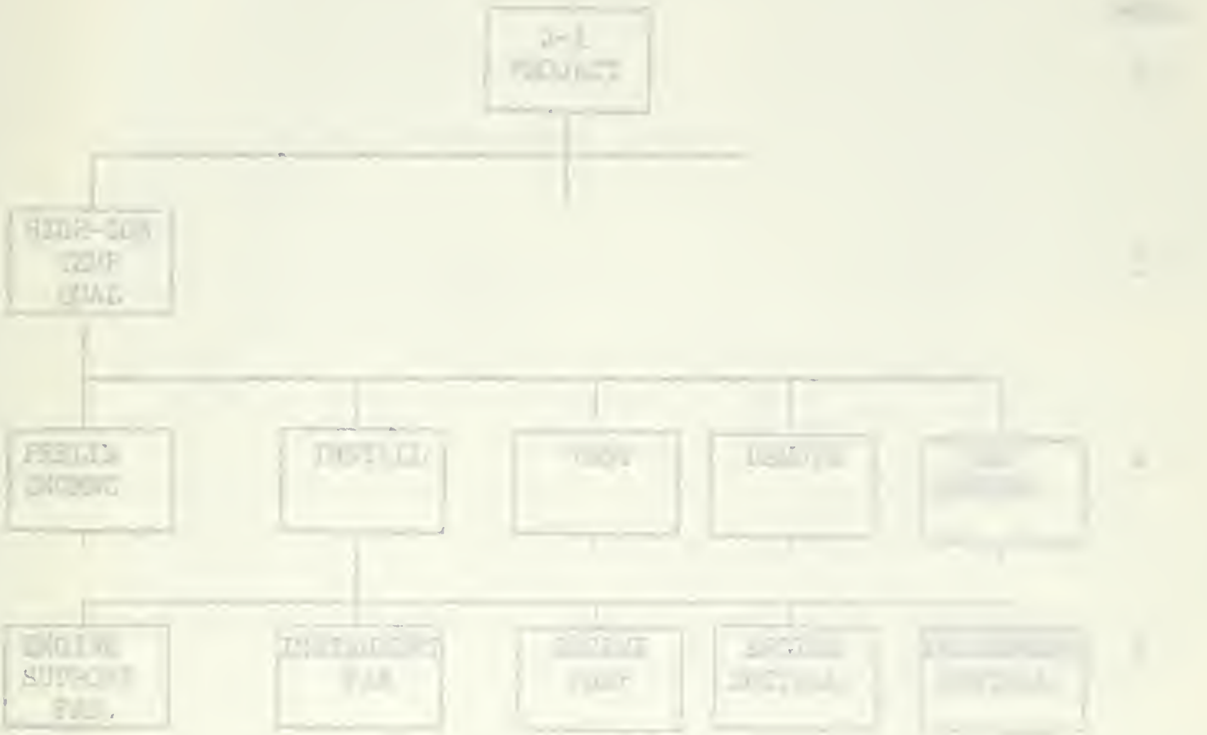

Figure 3.

WORK BREAKDOWN STRUCTURE

TO THE WORK PACKAGE

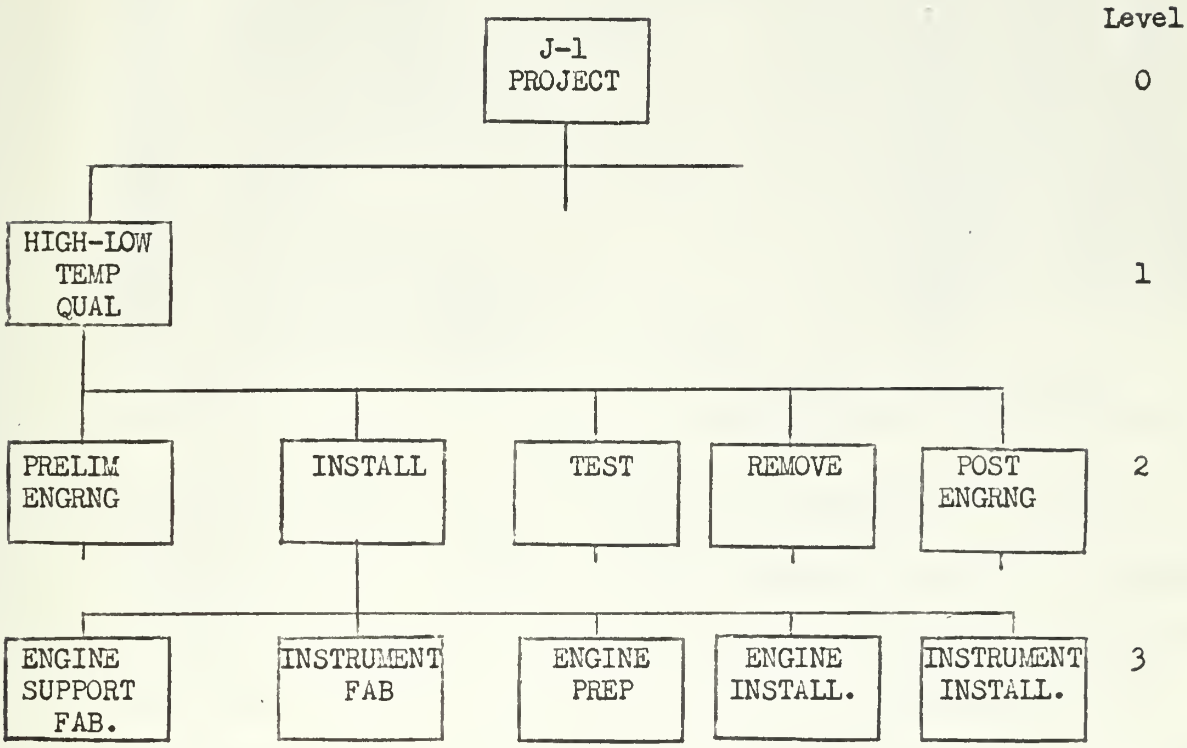

Figure 3.

TABLE 1

ACTIVITIES AND EVENTS

No.	Activity	Ltr.	Related Events
1211	Test Outline Preparation	A	Complete Activity 1211
1212	Instrumentation Engineering	C	Complete Activity 1212
1213	Engine Installation Engineering	B	Complete Activity 1213
1214	Programming	H	Start Activity 1251
1221	Engine Support Fabrication	D	Start Activity 1224
1222	Instrumentation Fabrication	E	Start Activity 1225
1223	Engine Preparation	D	Start Activity 1224
1224	Engine Installation	F	Start Activity 1231
1225	Instrumentation Installation	F	Start Activity 1231
1231	Test	G	Complete Activity 1231
1241	Removal	I	Complete Activity 1241
1251	Data Reduction	J	Complete Activity 1251
1252	Analysis & Report Drafting	K	Complete Activity 1252
1253	Report Publication	-	Finish
0	Zero-time constraint activities	-	--- -
----	- ---	Y&Z	Cell available

visually presents the planned sequence of accomplishment and the inter-dependencies involved. At this stage no estimating or scheduling have been done. Several significant points have been illustrated, however. The network visually displays the existence of constraints in the performance of the component jobs in the overall project. For example, Event F, the commencement of testing operations cannot be started until two activities have been completed: 1224, Engine Installation, and 1225, Instrumentation Installation.

Events F and G, and Events G and J, are joined by activity arrows labelled "O". These arrows represent "zero-time" activities - activities which require no use of resources and no passage of time. They indicate the constraint of Event F upon Event H and of Event G upon Event J, respectively. These artificial activities are required by the definition of a network. Their existence stems from the selection of events to be

J-1 ENGINE PROJECT NETWORK

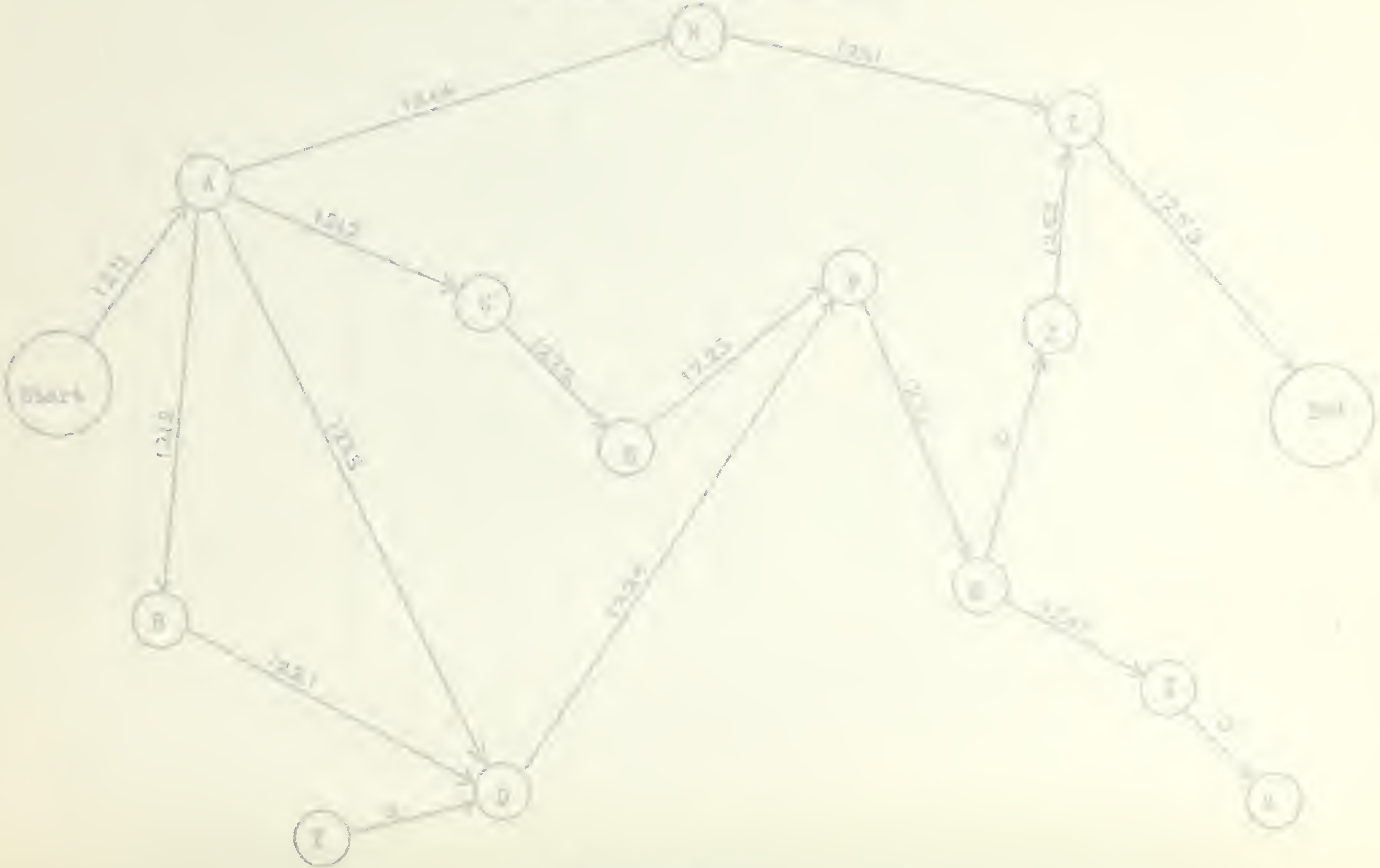

Figure 6-

J-1 ENGINE PROJECT NETWORK

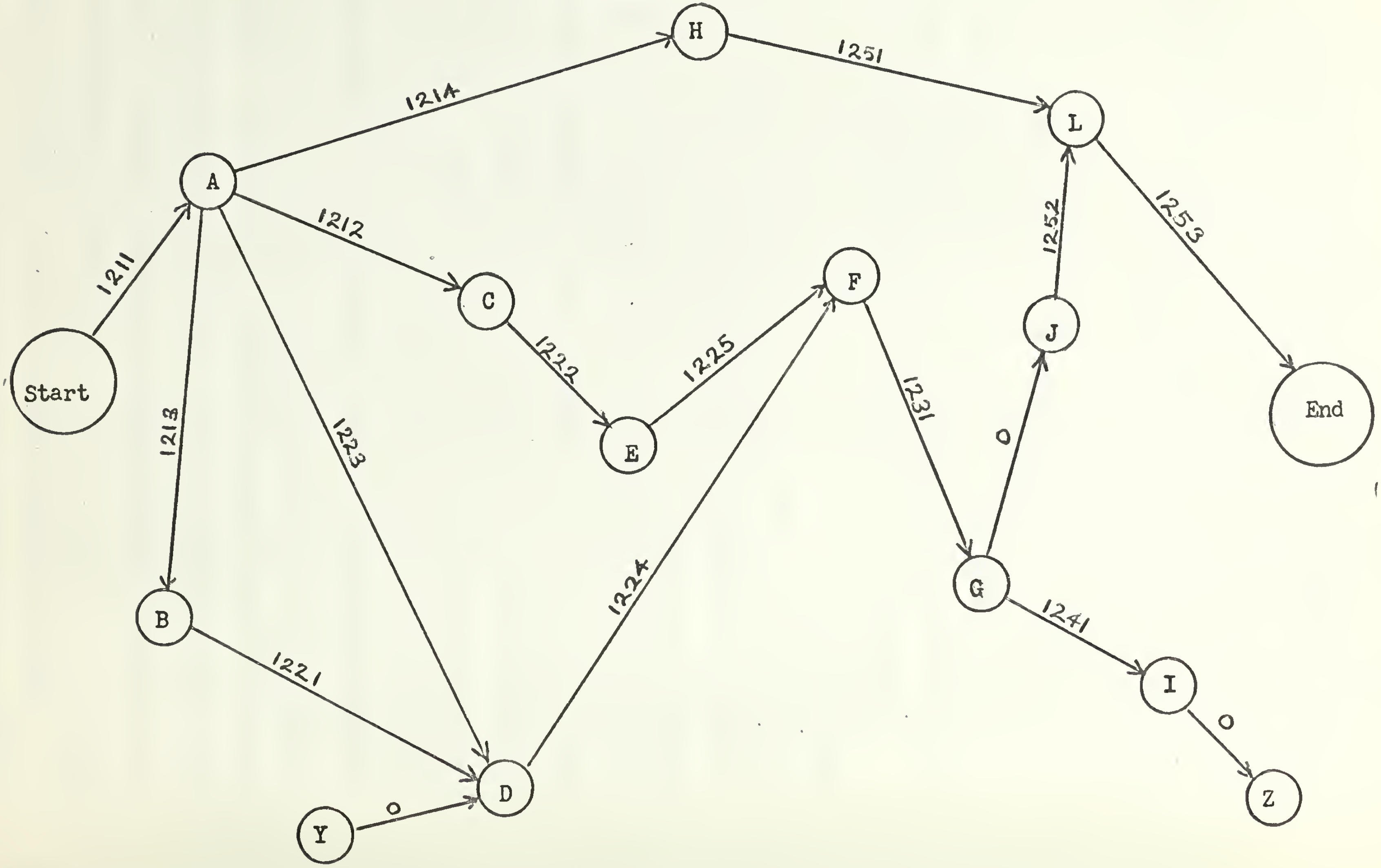

Figure 4.

recognized for planning and control purposes.

Event D is constrained by a zero-time activity from Event Y, and Event I is a constraint through a zero-time activity upon Event Z. These are illustrations of the concept of interface events. In large projects it is often desirable to prepare a number of separate networks to delineate the detailed plan of work for individual segments of a project. An interface event is an event common to more than one network.[3] While the interface events in the example are not part of a larger project, they still fit the definition: they are constraints imposed by one test project upon another by the limitations of plant capacity. Since the example test and evaluation station has only one sea-level test cell, engine installation (activity 1224) for the J-1 project cannot be commenced until the engine removal event of the project previously occupying the cell has occurred. Similarly, until Event I of the J-1 project has occurred, the follow-on project cannot commence its engine installation. The impact of such interfaces can be large if the uncertainties in any project on board a station are large.

The subject of facilities management is beyond the scope of this paper, but from the foregoing the usefulness of network analysis in test and evaluation facilities management can be seen. Networking the cell-occupancy events and activities of all test projects on board plus scheduled maintenance activities could provide an additional tool for increasing the efficient use of resources.

The next step in the analysis is preparing expected elapsed time estimates (te) for each activity in the network. Activities of high uncertainty should be estimated on the three-estimate basis. A single time

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[3] Ibid. p. 20.

estimate may be given for other activities. The estimates must be based on the planned availability of resources and the average rate of resource application. These time estimates should be made by the personnel in the organization most familiar with the activities. When the expected elapsed time (te) has been determined for each activity, they are then accumulated through each path to provide earliest expected time (TE) for each event. From an assumed beginning date, usually "now", each earliest expected time (TE) of the last activity is the TE of the project. Working this procedure in reverse from a predetermined target date - or a directed date (TD) from higher authority - provides in the same fashion the latest allowable date (TL) for each event. The latest allowable date (TL) for the first event is the latest date the project can commence without slipping the end event beyond the target date or the directed date (TD).[4] Figure 5 represents this stage of planning.

There are seven paths through the network:

1. Start-A-H-L-End,
2. Start-A-C-E-F-H-L-End,
3. Start-A-C-E-F-G-J-L-End,
4. Start-A-D-F-G-J-L-End,
5. Start-A-D-F-H-L-End,
6. Start-A-B-D-F-H-L-End, and
7. Start-A-B-D-F-G-J-L-End.

The path to interface Event Z is not significant to this project, but to the project that follows J-1 into the sea level cell. Using the elapsed time in weeks indicated beneath each activity line in Figure 5, each path has these

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[4] *Ibid.* pp. 22-24.

[illegible]

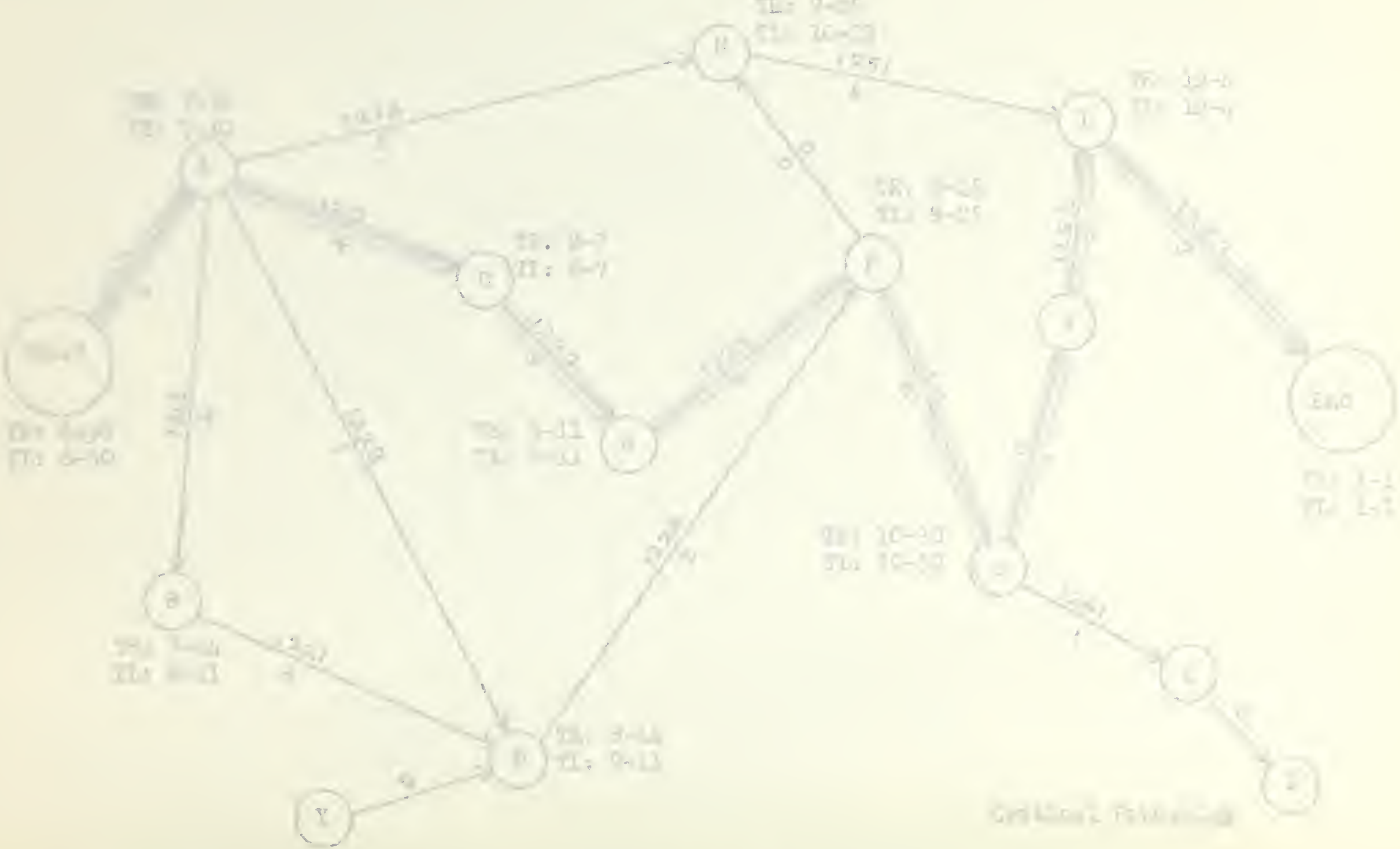

Figure 5.

J-1 ENGINE PROJECT NETWORK

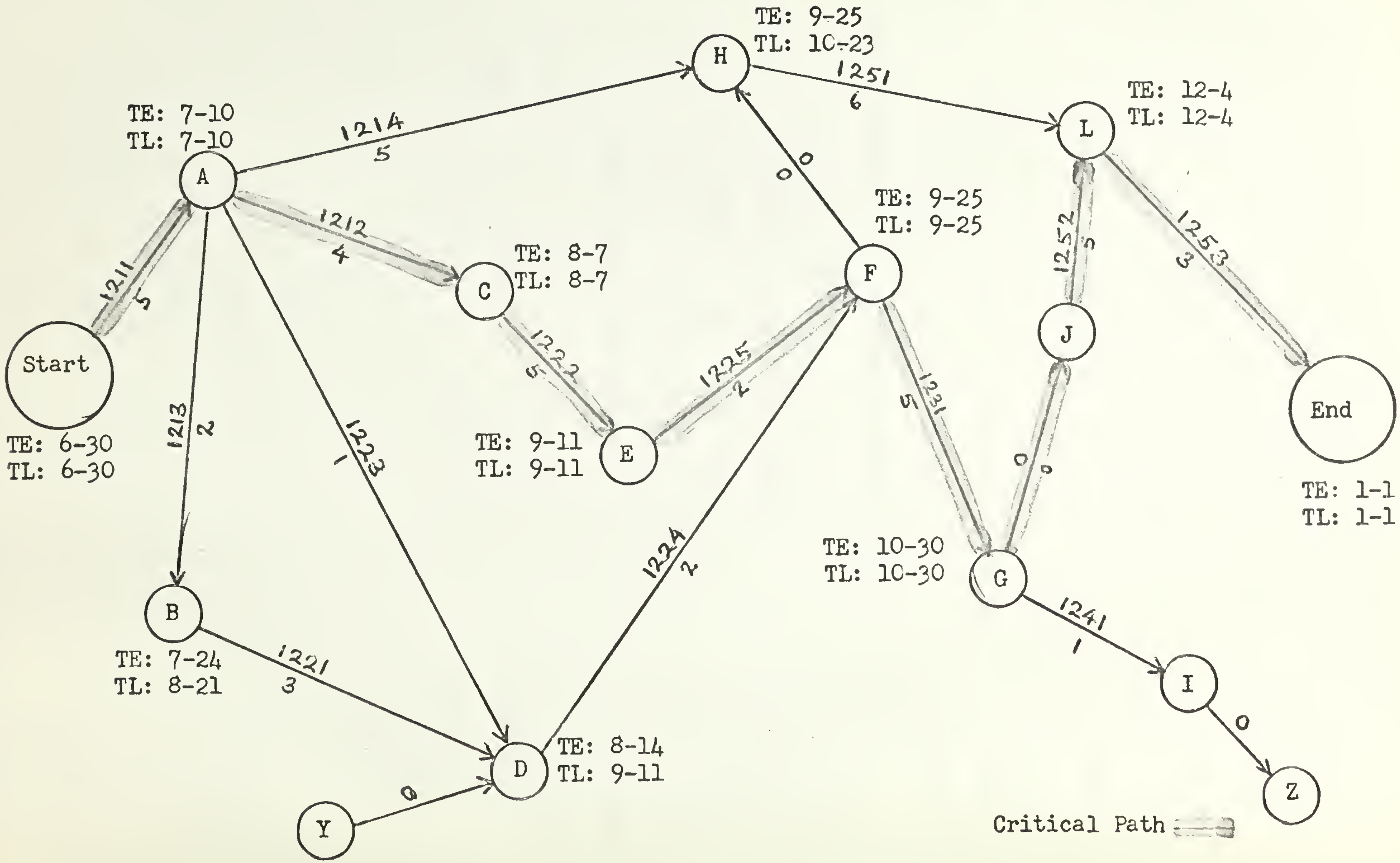

Figure 5.

elapsed times in weeks:

1	19
2	25
3	29
4	21
5	17
6	21
7	25

Path 3, through events A, C, E, F, G, J, and L, is the critical path. The slack in each of the other paths is the difference between their elapsed times and the elapsed time of path 3. Assuming that "now" is 1 June 1964, and that a target completion date of 1 January 1965 has been selected, the expected dates (TE) can be determined working from Start, and the latest allowable dates (TL) determined from End. Assuming no scheduled work from Christmas to New Year, TE and TL for the critical path are equal, and the elapsed-time slack in the other six paths is calendar slack, and is positive. TE and TL for each event have been indicated on Figure 5.

While the plan developed to this point demonstrates the feasibility of accomplishing the work by the target date (TD), it is nothing more than a plan. The plan must be validated through the scheduling process. Scheduling converts the plan into a feasible timetable having considered required manpower and facilities requirements during specific calendar time periods, conflicting demands for these resources, and the general sequence of the work.[5] When the plan has been scheduled, TE and TL will become earliest completion date (SE), and latest completion date (SL), respectively. Along the critical path the calendar dates will be the same

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[5] *Ibid.* pp. 25-28.

if the schedulers have accepted the plan as feasible. Along the other paths the scheduled earliest and latest allowable dates will fall somewhere within the slack of TE and TL, the actual dates depending on the influence of the considerations mentioned above. Should the scheduling invalidate the plan, replanning will be required. In either case, the scheduled dates, SE and SL, for each event will be computed in the same manner as were the expected dates, TE and TL. The scheduled plan is now a plan of action to be activated specifically and affirmatively in the routine manner the station uses to authorize and assign responsibility for work.

The cursory manner with which scheduling has been included should not be taken to suggest a minor role in the planning process. On the contrary, the validation of the initial planning through the scheduling effort of the lower levels of management is essential to the success of the planning effort. It is the interaction of the planning and scheduling process that provides a realistic plan; and it is the multi-level participation in the process that tends to provide multi-level support in the execution of the plan.

CHAPTER IV

THE PERT NETWORK: CONTROL

Control in the managerial sense is the comparison of performance against plan. Koontz has called planning and control "Siamese Twins", "singularly inseparable functions of managements".[1] The twin of the plan which was developed in the network analysis, then, must be a flow of information back to top management to show the progress of the action initiated by the plan against the plan.

Two opposing points of view occur in discussions of control under PERT. One holds that the PERT network should not be used as a control. The network in this view should not be used after the plan has been approved until a part or all of the project requires replanning. PERT-derived reports should be used for control. The network is like a map, and after the route is fixed it is easier to follow progress on a checklist of milestones.[2]

The opposite view holds that the network should be used as "a dynamic control mechanism". Since the network is used for scheduling and performance control (i.e. direction), it is better to use the network rather than some other set of subdivisions to control the project.[3]

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[1] H. Koontz, "A Preliminary Statement of Principles of Planning and Control" in P. M. Dauten, ed., Current Issues and Emerging Concepts in Management (Boston: Houghton Mifflin, 1962), p. 120.

[2] Stilian, et. al., PERT: A New Management Planning & Control Technique (New York: American Management Association, 1962), p. 11.

[3] Ibid. p. 43 and 46.

Though these two arguments purport to be opposed, they really deal with two different aspects of the control. The latter view, holding that the events in the network are the basis upon which progress reporting should be accomplished, deals with what should be reported. The former, asserting that tabulation of events is better report form than the network itself, acknowledges what should be reported, and deals with how.

PERT progress reports provide

1. Information on activities scheduled for completion during the reporting period,

2. A forecast of the activities scheduled for the next reporting period,

3. Any changes in the scheduled plan, and

4. Changes in estimated activity times.

This kind of information permits the assessment of deviations from the plan so that management can direct its attention to significant areas.[4] Thus, slippage in an activity in a path with positive slack may be evaluated as not significant and no further investigation or action would be taken. Conversely, slippage in an activity on the critical path would require that the manager seek more detailed information than is normally reported to his level to be able to arrive at a solution to the problem which will eliminate the delay anticipated for the slippage. Or the detailed analysis of the slippage may reveal that no acceptable corrective action is available, and a replanning of the network will be required.

All four of the details of activity progress listed above are necessary to a control system. Absence of information on activities scheduled for the current period leaves the forecasted information adrift

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[4] PERT Guide for Management Use, p. 32.

without a reference from which its significance can be assessed. Absence of forecast information and revised time estimates changes the progress report to a static historical status report of no value for purposes of control. The significance of these statements is that they impose additional information requirements on an organization. That is to say, the usual kinds of information being collected in the accounting systems of a naval activity are not in themselves useable for progress reporting for control purposes. It is the addition of the forecast to the current-status that provides the control feature. Otherwise management is only accepting a deviation from its scheduled plan as a fait accompli, and replanning is merely adjusting the plan by the amount of deviation which has already occurred.

Another point that should be made is that the generation of a progress report is only the first, and perhaps the easiest, step in the control system. It is when a deviation is observed and is evaluated as significant that the work of control begins. This is another way of recognizing Frederick Taylor's "exception principle"[5] of management. Koontz has elaborated this principle into what he calls "strategic point control".[6] Here, performance against plan is monitored routinely, even though there is no deviation, and even though action need be taken only if there is a significant deviation, for certain key indicators of the quality of planned performance. It can be seen that what has been described here is the routine progress reporting of milestones on the critical path of the test and evaluation project.

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[5] F. W. Taylor, Shop Management, (New York: Harper & Brothers, 1919) pp. 126-27.

[6] Koontz, "A Preliminary Statement of Principles of Planning and Control", p. 132.

Applying these statements to the example project, the following activities at least should be included in the control system:

1211 Test Outline Preparation

1212 Instrumentation Engineering

1222 Instrumentation Fabrication

1225 Instrumentation Installation

1231 Test

1252 Analysis & Report Drafting

1253 Report Publication

The computer-oriented PERT reports developed by the Special Projects Office cover all activities, or all events. And it may be argued that by the definition of events or milestones they are all "strategic points". Since sufficient slippage along any of the six slack paths could make them critical, all activities come within the concept of strategic point surveillance.

The frequency of control reporting must also be determined. It is a function of two considerations:

1. The requirement of the receiving manager.
2. Preparation time.

Logically, a control report should be in the hands of the manager requiring it in time to permit him to initiate action based upon that report by the time that action is needed. That is, when a deviation from the scheduled plan occurs, that fact must reach the manager who has the authority and responsibility to take action in time for him to analyse the deviation, determine its cause, determine alternatives to correct the deviation, select an alternative and direct the action required by the alternative in time to prevent the deviation from adversely influencing accomplishment of the

initial, or reworked, scheduled plan. This logical ideal would require a system instantaneously sensitive to deviation in an infinitely detailed scheduled plan. For practical purposes, the sensitivity of the control reporting system need only be suitable to the degree of detail in the plan against which it is reporting. In Figure 5 the activities in the network span from one to six weeks. Along the slack paths the shorter activities have slack of from one to nine times the activity length. Along the critical path Activity 1225 is two weeks long, and the rest are three or more. Since most normal naval effort is on a one or two shift-basis on a five day week, it would appear that a weekly control report system would provide adequate sensitivity for a project of this duration and size.

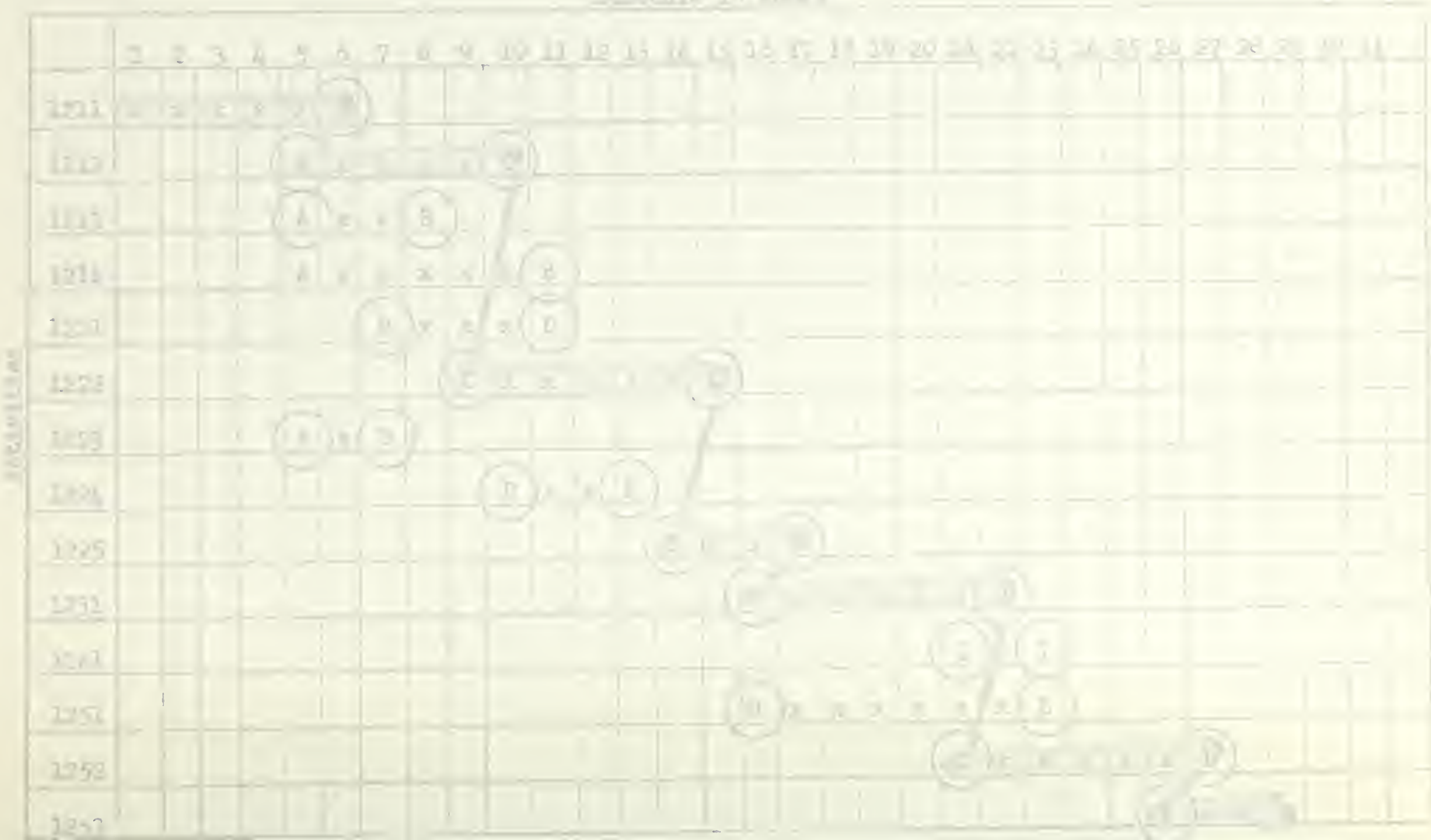
To provide a weekly progress report of all the activities in the network in time to be useful, determination of status and forecast of remaining work must be accomplished in a relatively short time, and then provided to the manager near the beginning of the next reporting period. Thus, it is desirable to provide as-of-Friday status and forecast by some time on Monday, so that action resulting from that report can influence the work in progress during the report period beginning that Monday. If it is not possible to prepare a control report for a weekly system about that fast, the "ideal" will have to be compromised with the "real", and a two-week cycle accepted. It can be seen from this line of reasoning that activity duration will influence the two basic considerations of report frequency.

But at the upper level of management, the milestones in the example network providing sufficient detail, a weekly system appears feasible.

To illustrate a progress reporting system for top management the J-1 project network has been converted to a simplified Gantt presentation in Figure 6. To facilitate illustrating the network slack it is assumed that

A-1 PROJECT TIME CHART

Schedule in Weeks



J-1 PROJECT TIME CHART

Schedule in Weeks

Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1211	x	x	x	x	x	A																									
1212					A	x	x	x	x	C																					
1213					A	x	x	B																							
1214					A	x	x	x	x	x	H																				
1221							B	x	x	x	D																				
1222									C	x	x	x	x	x	E																
1223					A	x	D																								
1224										D	x	x	F																		
1225														E	x	x	F														
1231																F	x	x	x	x	x	G									
1241																					G	x	I								
1251																H	x	x	x	x	x	x	L								
1252																					J	x	x	x	x	x	L				
1253																										L	x	x	x		

Figure 6.

all slack path scheduling developed the scheduled date (TS) to be earliest expected date (TE). All slack, then, is located on the right hand end of the activities in the slack path. To fit the precepts of progress reporting discussed on page 33, each weekly report would include for each event its

1. Scheduled completion week (date),
2. Estimated actual completion week (date),
3. Latest allowable completion date,
4. Remarks summarizing the problems causing reported deviations, their impact on other sequential work, their causes, and recommended alternative actions to eliminate or adjust to the deviation.

Such control reporting is illustrated in Figure 7. Note that this is an example of summarized information presented to top management for control purposes for one test project. It represents the culmination of successive summarizations of detailed estimations of how much work remains to be done in each activity and when, under prevailing conditions, it can be completed, beginning at the work center level with the supervisors and/or progressmen. The details of the presentation must satisfy the preferences of the managers to whom the reporting is addressed.

No naval test and evaluation activity has a workload as small as one test project at a time. Depending upon the volume and interrelationships of projects on board at any one time, it might be worth the effort to summarize project progress reporting to a consolidated summary.[7] Such a status summary could tabulate on one sheet scheduled dates, deviations, and slippage, for quick identity of projects to which more attention should be given. Figure 8 represents the kind of summary that would permit top management to bypass

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[7] B. Skaggs, "Network Modeling for Top Management", Data Processing for Management, VI, No. 2, (February 1964), pp. 11-16.

SAMPLE CONTROL REPORT

A-1 PROJECT MILESTONE REPORT

Project: [illegible]				As of: 9-1[illegible]			Date: 9-1[illegible]	
Event	S	E	L	JUL	AUG	SEP	OCT	NOV
A. Complete Test Outline	7-10		7-1[illegible]	S				
B. Complete [illegible]	7-31		8-?1	E C	L			
C. Complete [illegible]	8-7		8-7		SL C			
D. Start [illegible]	8-14		9-11		S	L E		
E. Start [illegible]	9-11		9-11			SL E		
F. Start Test	9-2[illegible]		9-2[illegible]			SL	E	
G. Complete Test	10-30		10-30				SL	E
H. Complete Programming	9-2[illegible]		10-27			S	L	
I. Complete Report	11-6		--					S
J. Complete Analysis	10-30		10-30				SL	
K. Complete Data [illegible]	12-[illegible]					Now		

[illegible]

Legend. S- Scheduled Completion. L- Latest Completion without delaying project. E- Estimated Actual Completion. C- Completed.

Figure 7

SAMPLE CONTROL REPORT

J-1 PROJECT MILESTONE REPORT

Project: 12. J-1 Hi-Low Temp Qualifications | As of: 9-11 | Date: 9-14

Event	S	E	L	JUL	AUG	SEP	OCT	NOV
A. Complete Test Outline	7-10		7-10	C				
B. Complete Engine Engrg	7-24		8-21	S C	L			
C. Complete Instru Engrg	8-7		8-7		SL C			
D. Start Engine Instl	8-14		9-11		S	L E		
E. Start Instru Instl	9-11		9-11			SL E		
F. Start Test	9-25		9-25			SL	E	
G. Complete Test	10-30		10-30				SL	E
H. Complete Programming	9-25		10-23			S	L	
I. Complete Removal	11-6		-					S
J. Complete Analysis	10-30		10-30				SL	
L. Complete Data Reduct.	12-4					Now		

Remarks: Engine Installation delayed due late receipt stressed test stand from NavShipYard Phila. Via express 9-15. Recommend slip critical path activities to new TE 1-6-64 at normal effort.

Legend. S- Scheduled Completion. L- Latest Completion without delaying project.
E- Estimated Actual Completion. C- Completed.

Figure 7.

on-schedule progress reports. Again the specific content of such a summary would depend upon the preferences of the individual receiving it. Highly summarized reporting would be likely to satisfy only commanding officers willing to depend to an extensive degree on the judgement and performance of his key subordinates. If this is not the case, preparation of such a report is a waste of time and effort, since he would only attend to other more detailed reports, or, in their absence, seek information through irregular channels.

In computer-oriented PERT reporting systems, the capacity of automatic data processing is such that given items of information can be quickly and economically presented in a variety of arrangements to facilitate managerial review. For example, event information can be tabulated in sequence of event, in sequence of expected date and sequence of slack.[8] Reports like these facilitate analysis of progress reports, and their usefulness increases as the size and complexity of the network increases. They are illustrated in Figure 9. In a manual system the constraint of economics is more rigorous, and the value of such reports to management will have to be weighed against the cost of preparation. Therefore, the PERT Coordinating Group's assertion that these reports are minimal[9] must be a relative evaluation, at least within the frame of reference outlined for this paper.

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[8] PERT Guide for Management Use. pp. 33, 34.

[9] Ibid.

SAMPLE CONTROL REPORT

CONSOLIDATED PROJECT SUMMARY

PROJECT	JUL 3	 10	 17	 24	 31	AUG 7	 14	 21	 28	SEP 4	 11	 18	 25	SCHEDULED COMPLETION
18. J-2 Icing Tests	-4				-4	-5			-5		-5		-1	7 Oct 54
19. J-2 Relight	-1				0	0			+1		+1		0	10 Nov 54
20. J-1 Water Ingest									0		0		0	15 Mar 55
21. J-1 Hi-Low Cycle			0		0	0			0	0	-1		-1	1 Jan 55
etc.														
Weeks ahead (+) or behind (-) [illegible] scheduled completion date														

Figure 8

SAMPLE CONTROL REPORT

CONSOLIDATED PROJECT SUMMARY

PROJECT	JUL					AUG				SEP				SCHEDULED COMPLETION
	3	10	17	24	31	7	14	21	28	4	11	18	25	
17. J-2 Icing Tests		-4			-4		-3		-2		-2		-1	7 Oct 64
19. J-2 Relight		-1			0		0		+1		+1		0	10 Nov 64
20. J-1 Water Ingest									0		0		0	15 Mar 65
21. J-1 Hi-Low Quals			0		0		0		0	0	-1		-1	1 Jan 65
etc.														
											NOW			

Weeks ahead (+) or behind (-) latest scheduled completion date

Figure 8

J-5 PROJECT EVENT REPORT

Date: 9-11 Sequence: Event

Event	Title	TE	TL	TS	Slack
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-26	+4
C	Complete Instrumentation Engrg	8-14	8-7	8-7	-1
D	Start Engine Installation	9-16	9-11	8-11	-1
E	Start Instrument Installation	9-23	9-15	9-11	-5
	etc.				

Date: 9-11 Sequence: ECD

Event	Title	ECD	TL	TS	Slack
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-26	+4
C	Complete Instrumentation Engrg	8-14	8-7	8-7	-1
D	Start Engine Installation	9-16	9-11	8-11	-1
	etc.				

Date: 9-11 Sequence: Slack

Event	Title	ECD	TL	TS	Slack
E	Start Instrument Installation	9-23	9-15	9-11	-5
C	Complete Instrumentation Engrg	8-14	8-7	8-7	-1
D	Start Engine Installation	9-16	9-11	8-11	-1
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-26	+4

Figure 5

J-1 PROJECT EVENT READOUTS

Date: 9-11 Sequence: Event

Event	Title	TE	SL	TS	Slack
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-24	+4
C	Complete Instrumentation Engrg	8-14	8-7	7-7	-1
D	Start Engine Installation	9-18	9-11	8-14	-1
E	Start Instrument Installation	9-25	9-11	9-11	-2
	etc.				

Date: 9-11 Sequence: TE

Event	Title	ECD	SL	TS	Slack
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-24	+4
C	Complete Instrumentation Engrg	8-14	8-7	8-7	-1
D	Start Engine Installation	9-18	9-11	8-14	-1
	etc.				

Date: 9-11 Sequence: Slack

Event	Title	ECD	SL	TS	Slack
E	Start Instrument Installation	9-25	9-11	9-11	-2
C	Complete Instrumentation Engrg	8-14	8-7	8-7	-1
D	Start Engine Installation	9-18	9-11	8-14	-1
A	Complete Test Outline	7-10	7-10	7-10	0
B	Complete Installation Engineering	7-31	8-21	7-24	+4

Figure 9

CHAPTER V

MANUAL PLANNING AND CONTROL

The previous chapters have summarized features of network systems, described a representative test and evaluation project, developed the planning network for it from higher management's point of view, and related to that plan a progress reporting system. It is now necessary to put these elements into the frame of reference - non-automated management planning and control.

The literature of planning and control probably contains as many tabulations of principles or characteristics of these functions as there are writers. Many are common, and many that differ are really just differences in terminology. From this variety, some of the principles or characteristics seem to be the major or most imperative ones, and it is against these that a system should be tested for adequacy.

Planning has been characterized as a choosing among alternatives to seek a consistent, integrated, and articulated program to achieve a selected objective or goal. Control, then, seeks to compel events to conform to the plan.[1] This expression of the two functions emphasizes their "Siameseness". Insofar as they can be separated, planning would appear at least initially to have to precede control.[2]

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[1] B. Goetz, Management Planning and Control (New York: McGraw-Hill, 1949) p. 2.

[2] Koontz, "A Preliminary Statement of Principles of Planning and Control." He calls this the principle of primacy of planning. It seems tautological.

Planning for a test and evaluation project must begin with receipt of the assignment of the project. This may be a piece of paper from the management bureau, or it may be information received in advance of the formal assignment. In either event the initial planning will involve the identification in broad terms of what is to be done, when it will be done, and how it will be done. As the project is broken down into component parts, successively lower levels of management should be involved, down to the point where the work packages or activities which relate to the organizational units principally responsible for their accomplishment have been identified. As the work packages are identified and their relationships and sequence of performance determined, the network will take shape. The levels of management brought in will assess the work involved and estimate the elapsed time required. Then these managers will take their work packages further down in the organization for detailed scheduling. Returning back up the planning chain, the results of the scheduling will be used to adjust the initial feasible plan on implementible form - a scheduled plan, in PERT terminology.

The system summarized here and described in Chapter II and III exhibit some of the major characteristics on the planning function. First, the plan focuses action on the purpose or objective of the project. Each of the activities in the network have been identified as necessary steps in the achievement of the final goal. The plan is therefore an effective plan.[3]

One of the advantages of PERT systems is their systematic approach to planning, and their ability to bring to light the dependencies and

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[3] C. Barnard, The Functions of the Executive (New York: Pitman, 1949), pp. 231-33.

interrelationships of the various pieces of effort that go to make up a project. The result of the planning effort is a scheduled plan of action which has attempted to identify all contingencies in advance to arrange the flow of work to allow for them. Second, then, the plan may be said to be efficient.[4] That is, it is intended to attain the objective with a minimum of unsought consequences, and with a lesser expenditure of resources than would otherwise occur.

Third, the scheduled plan is constructed by the joint effort of all the levels of the organization with responsibility for accomplishment. This has been called the principle of the pervasiveness of planning.[5] It incorporates the logical idea that the best way to engage a man's interest in the execution of a task is to involve him in the planning of it. This would seem especially valid if praise and blame accrued to his performance in terms of the tasks he himself partly planned. Thus, while it may be said that PERT scheduled plans involve all levels of supervision to insure their accuracy and validity, the benefits of the incentive aspect follow as well.

The availability of these characteristics of a good planning system found in PERT is facilitated by the feature of test and evaluation projects mentioned previously. That is, their relatively narrow scope and relative repetitiveness in general outline. These two features permit the use of some of the PERT techniques which under other circumstances would require the services of automated data processing facilities. The J-1 engine project was broken down into sixteen real-effort activities plus four pseudo-activities, arranged in seven paths in the project network. If all fourteen real activities had involved uncertainties requiring the three-estimate method, it can be seen that the determination of most likely

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[4] *Ibid.* p. 123.

[5] Koontz, p. 122.

times, the critical path, slack, variations and standard deviations, would not be an unrealistic burden to impose on humans with desk calculators. Further, it can be visualized that in the event that the expected completion date (TE) was later than a directed date (TD), the computations required to assess the application of alternate levels of effort on various activities would still be within the practical limits of a manual system, even if a dozen alternatives were tested.

Estimates vary as to the size of a project that can be dealt with manually. One source asserts that manual routines can handle critical path, subcritical path, and slack times determinations for networks or aggregates of networks ranging from fifty to "several hundred" events.[6] Another asserts more definitively that manual methods are "worth the effort in networks up to 200 events".[7] Without selecting one assertion as the right one, it can be seen that the hypothetical J-1 project can easily be handled manually. Indeed, if each of the work-packages in the example were PERTed into component detailed tasks of fourteen events each, the entire network would represent only 196 activities. Or, if ten test projects for the sea-level test cell were all networked to the same detail as the J-1 project, had about the same duration, and were related through the interface events into a master test cell network, some eighty weeks of planned test cell time would be represented in a 140-event network. Even within any given network size, the amount of effort involved can be varied by the degree of detail demanded of the system.

If the relatively small size of test and evaluation networks

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[6] Bursk and Chapman, New Decision-making Tools for Management. p. 167

[7] W. Hunter, Navy Management Office. "The PERT System", lecture to Navy Graduate Financial Management Program. 5 December 1963.

facilitates the non-computer approach, the relatively narrow scope and tendency to recurrent effort does so also. This is not to say each test and evaluation project of a given class of equipment is exactly the same as its predecessors. If this were found possible it would only mean that each engine or catapult or hull form was exactly the same as its predecessor, and the only testing then required might be some quality control testing of samples of a production run. On the contrary, the test and evaluation function is required by the fact that successor equipments are different, that failures in service do occur from different causes. However, as is exemplified in the hypothetical J-1 project, the kinds of effort required seem to fall in a general pattern. That this is so tends to reduce the total networking effort to the degree that the recurring pattern is promptly recognized, and previous experience expedites the details of planning. Further, it may be argued that the span of PERTing in a manual system can be extended by the development of a model network, or a collection of model networks, one for each of the several classes of test and evaluation projects identified at the station.

The use of a typical or established pattern of carrying out projects can speed up the early phases of planning, an advantage especially valuable when tight deadlines force some concurrency of planning and execution.

The Defense Systems Department of General Electric Company uses a model system for the preparation of contract proposals, which generally must be accomplished in about thirty days. To expedite proposal preparation, the common features are exploited to develop a standard network and a glossary of standard work activities. A third planning aid is a dummy work statement, in this case a model Request for Proposal.[8] The proposals

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[8] A. McHugh, "Using PERT for Contract Administration" in Stilian, et. al., PERT: A New Management Planning and Control Technique. p. 118.

prepared with these aids themselves contain up to 1600 to 1800 activities.

If a model project, a model network, and a glossary of activities can help large projects under rigorous time constraints, these aids can facilitate manual PERTing. There are hazards involved. One of the objectives of PERT is the production of a valid network which is meaningful to those who are going to execute the plan.[9] In the Defense Electronics Division of General Electric Company, where projects tend to be more diverse, experience showed that standard event titles (the glossary device above) delayed and confused planning because of the time spent trying to decide which standard titles were appropriate to the project under consideration.[10] It is interesting that these opposite conditions occurred in different divisions of the same corporation. This is taken to illustrate the diverse character of managements, and supports the argument that such a device is at least worth a trial where projects exhibit a degree of similarity.

Recognizing that no two projects are exactly the same, and that different project directors and project engineers will have a different approach to building a network, too rigid an adherence to what should be guides or aids can compromise meaningful networking. Standard networking must therefoe allow for modification to adjust to changing project details and personnel.

To say that control seeks to compel events to conform to plan is in a sense to combine the sequential ideas of control and redirection. It is the controls which stimulate the redirection that is of concern here. In

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[9] Bursk and Chapman, p. 106.

[10] H. G. Francis "Practical Advice for the Use of PERT" in Stilian et. al., PERT: A New Management Planning and Control Technique, p. 131.

this frame of reference, Henri Fayol's statement that control is verifying that everything happens as was planned[11] is more appropriate. Control requires a flow of information to the level where the control is being exercised. This flow is accomplished by reporting.

The characteristics of control reporting in the literature evidence the same variety as of planning, and therefore may be discussed in a similar manner. If control seeks to compel events to conform to plan, the control information must be in terms of the plan. The general character of PERT progress reporting reflects this imperative. The activities and events in the project network are the terms in which the project is planned. Therefore, control reporting is these terms. Another aspect of control reporting is the requirement of organizational suitability.[12] This concept holds that if managers and supervisors are the means by which activities are accomplished, the controls must suit the organizational arrangement of responsibility.[13] The nature of the PERT work breakdown structure is such as to satisfy the demands of both activity and organizational suitability. One corporation meets this idea quite explicitly. In the system used at the Space Guidance Center of IBM, control report printouts for every responsibility level include the name of the manager to whom the control data is being summarized. This small addition to the computer program is intended to stimulate the personal interest of the individuals involved in each project.[14] Participation in control reporting parallels and

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[11] Koontz, "A Preliminary Statement of Principles of Planning and Control", p. 120.

[12] *Ibid.* p. 132

[13] L. Urwick, The Elements of Administration (New York: Harper & Bros., 1943), p. 107.

[14] Bolen and LeDuc "PERT/Cost Case Study", lecture.

reinforces participation in the planning function.

In addition to orientation to the work structure and the organization structure, progress reports must be oriented to time. The report will state what has been done as of the cutoff date of the report. That is, it will reflect historical data. But since control is aimed at correction of deviations and/or preventing future deviations, the report must also address itself to future periods. This principle of future controls[15] is embodied in PERT progress reporting as exemplified in the samples in Figures 7 and 8. The significance of this kind of information in control reports emphasizes the importance of its accuracy. If slippage is reported as of the report date and the forecast shows the slippage being overcome before the scheduled completion date, no action will occur at higher management levels. Assuming no other adverse circumstances arise, if the slippage does in fact - that is, the forecase was inaccurate - then the advantage of the early report of slippage would have been lost. Conversely, forecasting slippage when it will not in fact occur reduces the range of alternative choices management may consider in solving some other slippage. This is not to say that inaccuracies are intolerable, for such an attitude would be unrealistic in the extreme, but rather it emphasizes the need for conscientious forecasting as opposed to careless "shot gunning" or biased reporting for self-protection or self-aggrandizement.

Reporting outlook for subsequent reporting periods will, because of the need for timeliness, be approximate. The accuracy of such approximations will depend on adherence to the imperative discussed above of reporting up through all involved levels of the organization. For example, suppose that Activity 1221, Engine Support Fabrication, for the J-1 project involves seven interrelated items of work in two work centers, as

illustrated in Table 2. The estimation of progress and the forecast of completion of each of the items can best be done by the work center supervisors who are responsible for the work items and are supervising their accomplishment in the environment of the total workload of their work centers over the time period involved. The Service Shops manager can then assemble these estimates into a forecast of the activity progress to present to the Project manager, and so on upward in the organization (see Figure 1, page 20, and Figure 3, page 24).

TABLE 2

WORK ITEMS, ENGINE SUPPORT FABRICATION

Work Center	Item	Description
Sheetmetal	A	Fabricate Inlet Air Labyrinth Seal
Sheetmetal	B	Send A to NavShipYard Phila. for stress relief
Machine	C	Machine Adaptor and Seal of A
Sheetmetal	D	Fabricate Inlet Air Duct for A
Machine	E	Machine flanges on D
Sheetmetal	F	Modify engine stand
Machine	G	Machine and drill stand to take Duct.

In discussing control, the idea of redirection was removed. This idea ties the twins of planning and control together. If a plan is prepared to do a job, and controls are used to measure accomplishment against the plan, then redirection, or navigational change[16], or recycling[17], is the dynamics of the relation between these two concepts. When performance deviates from plan, either adjustments at the operating level must be made,

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[16] Koontz, p. 123.

[17] _PERT Guide for Management Use_, p. 36.

of some degree of replanning--and rescheduling--of the plan must be performed. It is in this recycling process that the involvement of each level of responsibility in planning and then in progress reporting pays off. Indeed, this involvement can be said to be the key to the use of network concepts in non-automated systems.

Two statements distill the idea of participation as the key to success in taking advantage of PERT techniques without automatic data processing. Learned states:

> The effectiveness of a control system is in large measure determined by the extent to which it has been incorporated in the daily routines and expectations of the personnel affected by it.[18]

The PERT Coordinating Group asserts at the outset in its PERT Guide that a management tool or technique no matter how sophisticated is only a tool and can never be a substitute for effective managers.[19] Parenthetically it may be observed that such a tool may, however, help reveal ineffective managers.

The mechanics of the techniques so far described should not obscure the fact that they are only techniques, intended to facilitate the flow of information and prevent oversights and inaccuracies, to structure information flow in a more precise and useful manner. In the absence of the speed and capacity of computer systems, this point is doubly important. The data developed in a management planning and control system based on the PERT concepts must move through the levels of management involved in time to be useful for the purposes for which developed. The reason the illustrations in this paper are not smoothes into completely developed forms is to avoid the implications of "formitis". It is the information contained in them that must move, not the forms. In discussing PERT reporting Stilian observes that information is transmitted on a more timely basis by word of

mouth at planning and control meetings.[20] This method will certainly suffice where these techniques are engrained in the organization's daily routines. Even in the computer-oriented system of the Special Projects Office, the Milestone Progress Repoting System for the POLARIS project included weekly or bi-weekly reporting by telephone to insure the timely receipt of information. Standard form reports were submitted afterwards by mail for confirmation purposes.[21]

The importance of the principles discussed in these pages cannot be over-emphasized. Progress information must be developed in terms of the planning done. The personnel involved in a project must be brought to the condition of routinely dealing with the project in the terms in which they themselves planned it. Progress reports must be delivered where they are needed when they are needed by whatever means gets them there in time to be useful. To the degree such reporting is desired on a formal basis, this should be done on a confirmation basis if it would otherwise interfere with timely reporting.

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[20] Stilian, et. al., PERT: A New Management Planning and Control Technique, p. 85.

[21] Special Projects Office Program Planning and Control System, Washington, D. C., 1958. p. 19.

CHAPTER VI

THE ADDITION OF COST[1]

Management not only views its tasks from a schedule point of view, but also concerns itself with the costs of accomplishing its tasks, both in an absolute sense and, because of the finiteness of the resources available, in relation to the schedule. The Critical Path Method, CPM, separates planning from scheduling, and in the scheduling phase deals with both time and costs as interdependent functions. Basic PERT integrates planning and scheduling on a time basis, with the feature of being able to develop probabilities for the estimates of project duration.[2] While scheduling the PERT plan is done in terms of time, cost - insofar as it involves available manpower - is unavoidably, if indirectly, involved in the effort by the schedule terms described in page 10. To explicitly recognize cost considerations and integrate them into PERT planning and control, the Department of Defense and the National Aeronautics and Space Administration have developed guidelines for a uniform PERT/COST system. As with the original Special Projects Office PERT technique, PERT/COST is primarily computer-oriented, though not restricted thereto. In the same way that it was earlier argued that the advantages of network time systems should be available to smaller efforts without the services of ADP, so too should

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[1] The description of costing is based upon DOD and NASA Guide, PERT COST Systems Design, Washington, D. C. June 1962. p. ii.

[2] Stilian, et. al., PERT: A New Management Planning and Control Technique, p. 147.

developments in cost planning and control be available.

To oversimplify, PERT/COST is merely the addition of cost estimates to the TIME network, and the subsequent collection and reporting of cost data for control purposes. Practically, however, several judgements must be made in determining the frequency and detail of reporting, and, from this, the detail in costing the network. Logically, these judgements will relate to

1. The duration and approximate cost of the project,
2. The degree of uncertainty in the work,
3. The degree of detail in the network,
4. The data-handling capacity of the accounting system,
5. The ability of the accounting system to absorb additional classifications of data,
6. The usefulness of the information potentially available from the accounting system, to the managers involved.

Again using the hypothetical J-1 engine project to illustrate, the planning process develops a work breakdown structure to the work package level, and a network of the interrelationships of the work packages (activities). The scheduling process which begins at this point can now be performed with detailed cost estimation. Costing must begin from the bottom of the work breakdown structure with the people who are actually going to do the work. The formulation of cost estimates in terms of direct man hours and material requirements will be in more detail than will be warranted for control reporting purposes. For example, each of the work items shown in Table 2 on page 51 will be estimated in detail by the two work center supervisors. The labor estimates will be prices out at the applicable wage rates, the materials prices, and the total taken to represent the cost

estimate of Activity 1221. At some naval activities this kind of estimating is performed by a "planning and estimating" unit, in which event the work center supervisors must be afforded the opportunity to accept - that is, commit themselves to - the estimates, or to modify them to the point where they will agree that they can accomplish the work within the estimate. At this point a work center manpower loading analysis will permit scheduling of Activity 1221 as described on pages 30 and 31. In similar fashion all of the activities are costed for direct labor and material, and scheduled. From this effort, a scheduled and priced network for the project is developed. Figure 11 illustrates the build up of the costs for the J-1 Project.

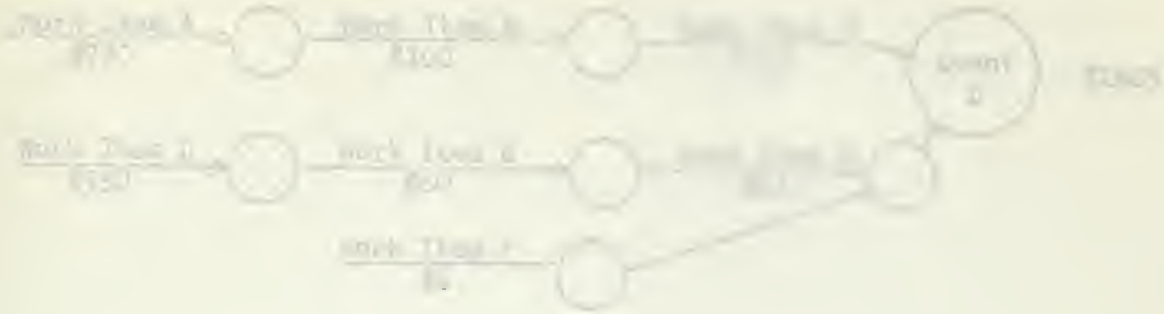
Control is exercised through progress reports showing progress against plan, and forecasting the work remaining. Here the constraints of the information system and the needs of management must be balanced to determine what reporting will be useful and timely. Without limit on data processing ability, the project network could be expanded to include each of the work items in each activity. Even if this were feasible however, it might not be useful, because individual items are not cost significant in relation to the project. For example, work item B, stress-relieving the inlet air labyrinth seal on a known-price Work Order to the Philadelphia Shipyard for $100, is not cost significant since the estimate is not subject to significant variation and is not a significant proportion of the Activity.

The DOD and NASA Guide asserts

> The level of detail to which it is desirable to apply the PERT/COST system is largely a matter of judgement, and varies from project to project, from one part of a project to another, and from the proposal preparation to the execution stage of the same project. As such, it is unrealistic to specify a predetermined level of detail....for applying PERT/COST....Rather, the level should be determined by the program or project manager, and should be a function

[illegible]

[illegible]


Work Item A
$75
Work Item B
$100
Work Item C
Event
$305
Work Item D
$150
Work Item E
$50
Work Item F

[illegible]

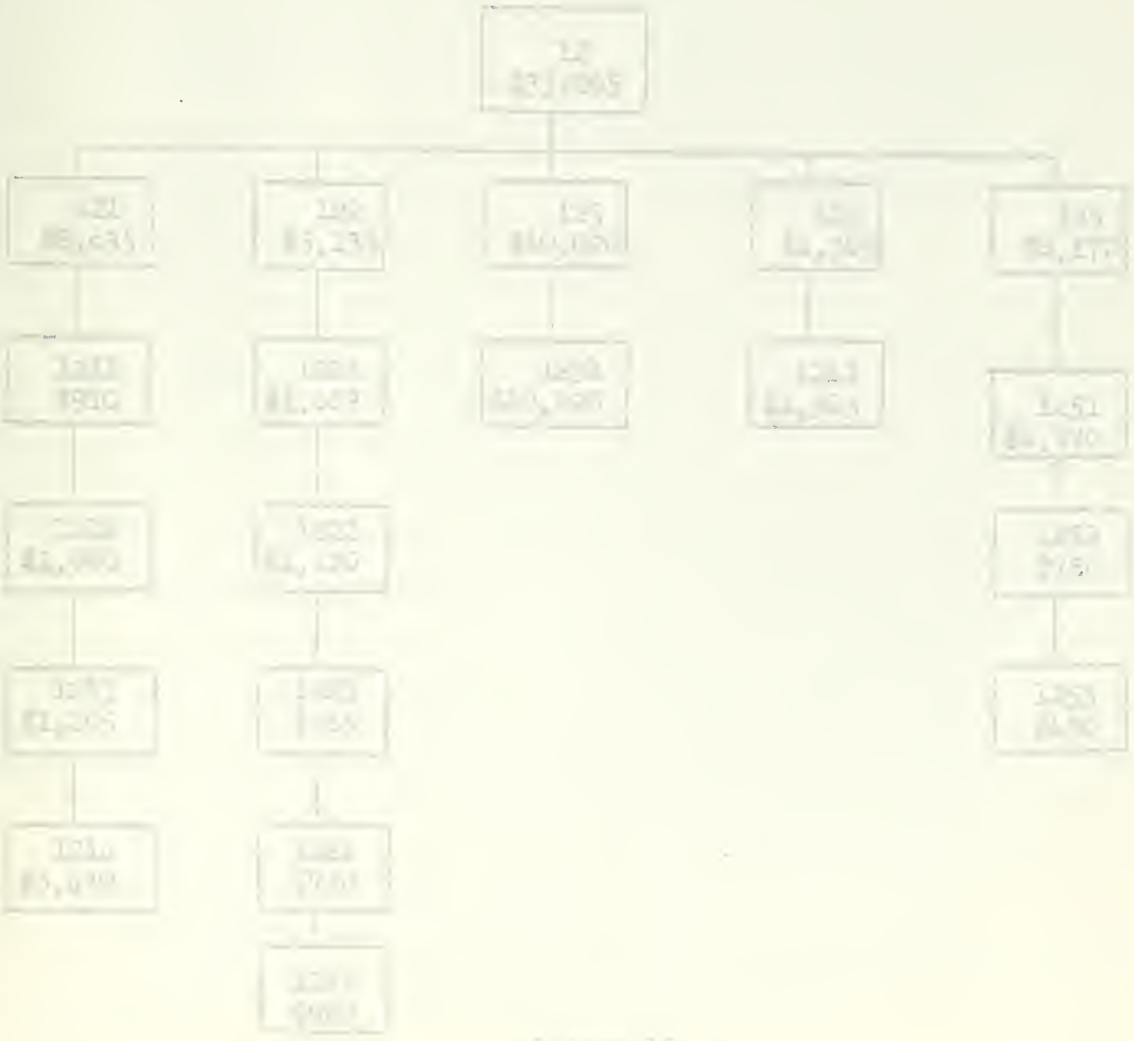
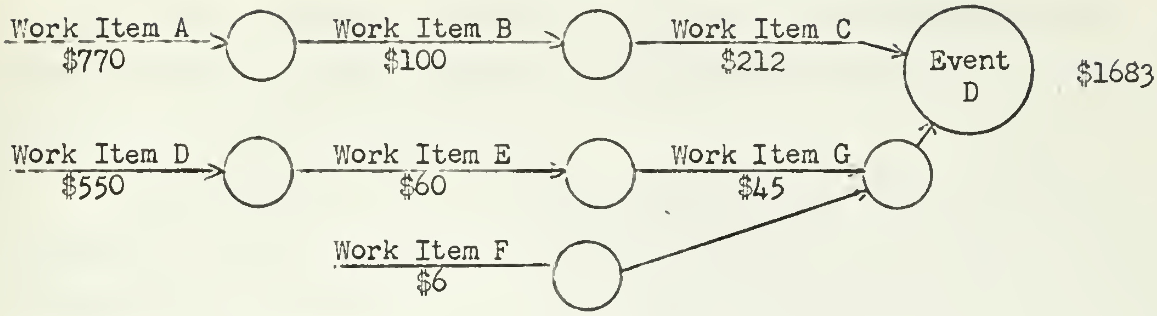


Figure 10

PROJECT COSTING

J-1 HIGH-LOW QUALIFICATION TEST



Activity 1221

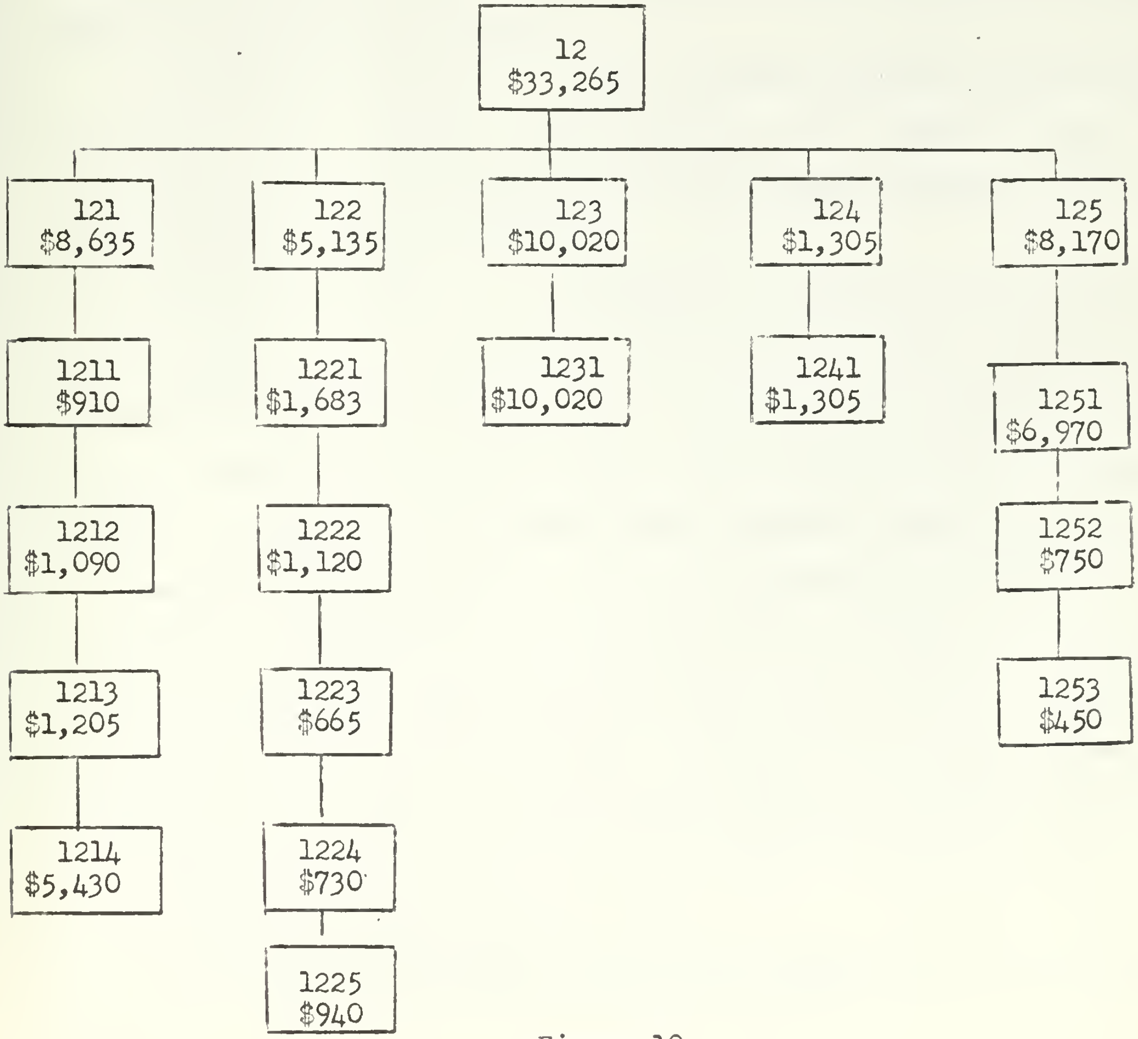


Figure 10

> of such factors as: the size and complexity of the project, the degree of uncertainty of the work, the familiarity with the work to be performed, and the time available for planning.[3]

Here again, as argued in the Basic PERT discussion, the relatively narrow scope and relative repetitiveness of the test and evaluation projects at one station mitigate in favor of a degree of predetermination and standardization, and the restricted data processing capability requires that these limitations be exploited.

The question here is not what data can be gathered, but what information can be assembled for progress reporting in a timely fashion. Standard navy requirements for appropriation accounting, payroll expenditure and object class accounting, together with common job order methods for responsibility and cost accounting purposes provide labor and cost classifications which with only slight adjustment will furnish sufficient data for project cost control.[4]

An example of part of a simple job order system is diagrammed in Figure 11. It is a segment that relates to the J-1 engine project, and does not reflect all of the classification that would be required for all internal and external reporting requirements.

With the variety of data avilable, a selection for progress reporting must be made. It can be asserted on the face of it that a weekly reporting of detail through all levels from the work item level upward for cost control purposes would be an unrealistic and unattainable goal in a non-computer system. However, having selected weekly schedule progress reporting, cost reporting to similar levels on the same frequency may be selected. Here again, the question of cost significance must be reviewed. In the J-1 project, $33,265 in direct costs is planned, over a 29 week period. Assuming an even flow over the duration of the project, the average weekly rate would $1,147. It would appear doubtful whether meaningful variances from this

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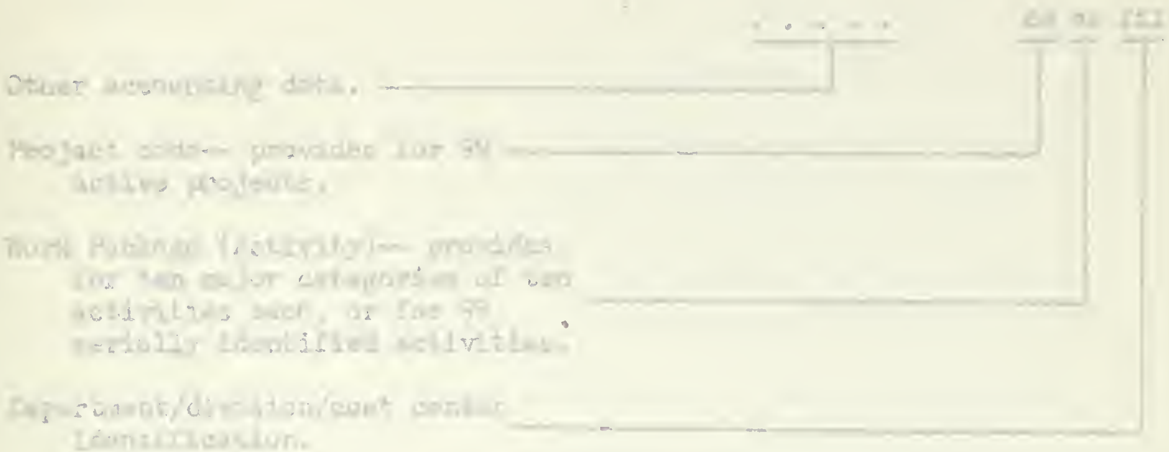
[3] PERT COST Systems Design, p. 33.

[4] Financial Management in the Navy, Washington, D. C.: Bureau of Naval Personnel, 1962. pp. 125-132, 145-155, 167-177.

EXAMPLE ACCOUNT CLASSIFICATION

CODING STRUCTURE


. . . . .
XX XX XXX
Other accounting data.
Project code-- provides for 99 active projects.
Work Package (Activity)-- provides for ten major categories of ten activities each, or for 99 serially identified activities.
Department/division/cost center identification.

Details of this structure will depend upon the data sorting method used in the data processing organization.

A position-coded system for the J-1 project would appear as:

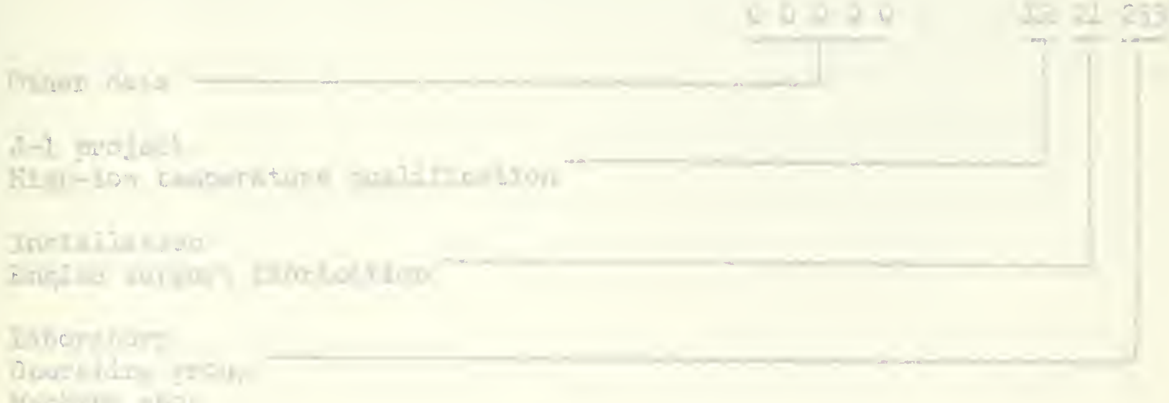
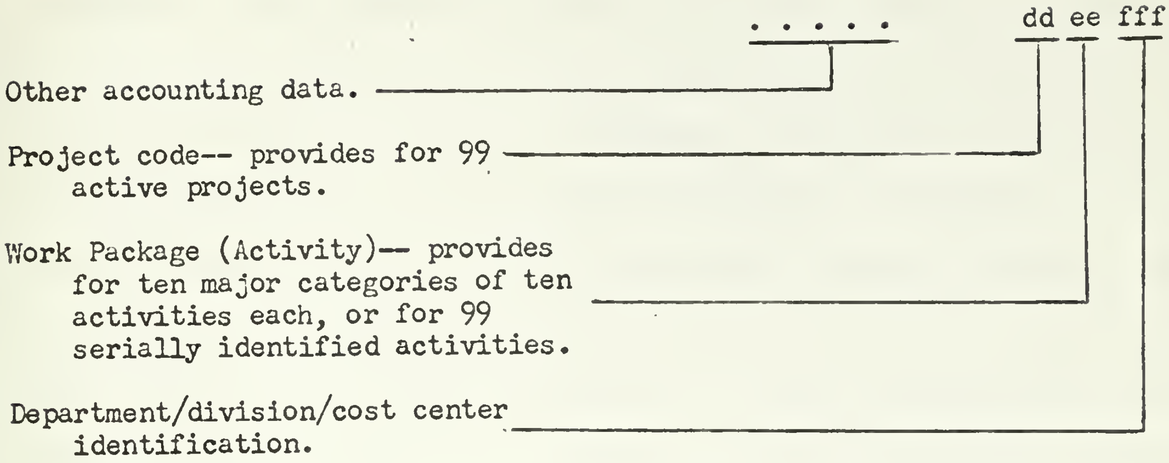


Figure 11.

EXAMPLE ACCOUNT CLASSIFICATION

CODING STRUCTURE



Other accounting data.

Project code-- provides for 99 active projects.

Work Package (Activity)-- provides for ten major categories of ten activities each, or for 99 serially identified activities.

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Details of this structure will depend upon the data sorting method used in the data processing organization.

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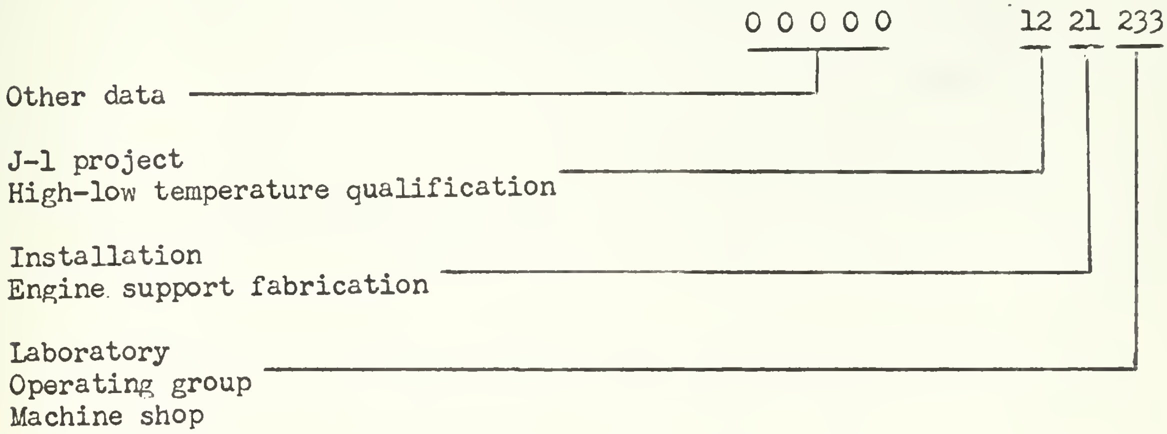

Other data

J-1 project
High-low temperature qualification

Installation
Engine support fabrication

Laboratory
Operating group
Machine shop

Figure 11.

amount could be detected since the level of detail for planning purposes was only down to the work package - activity - level and deviation from schedule may well be only a change in the location in time of the direct dollar flow, not a change in actual costs. On the other hand, weekly status, while not significant in itself can be useful over time in indicating to top management trends in the flow of dollars. The usefulness of such static information will depend upon the accuracy of the plan against which actual cost is plotted. For instance, in the case of Activity 1221, operating personnel might requisition and position the material required for the Activity in advance of any significant manpower expenditure. Such deviations from a straight-line flow of resources would have to be reflected in a status report. Figure 12 illustrates a graphic presentation of direct cost status on a weekly basis. The time axis has been matched to Figure 6 on page 37, and the timephased COST plan was built from the table in Figure 10, page 57. The prepositioning of materials at the beginning of the installation Activities is represented by the "humping" of the plan line in that time period.

In the discussion of control in Chapter IV it was argued that progress reports for control required both status and forecast information. The cost reporting discussed above does not reflect any forecast of future performance. A mechanical application of schedule variance reported in the Sample Control Reports in Figures 7 and 8 would merely shift the position of cumulative actual cost levels along the time scale. In order to include meaningful cost forecasts in control reports, it is necessary to report the dollar cost originally planned for the amount of work actually accomplished to date. The DOD/NASA Guide, dealing in terms of government contracts, refers to this kind of estimate as "contract estimate for the work performed (progress) to

J-1 PROJECT DIRECT COST STATUS

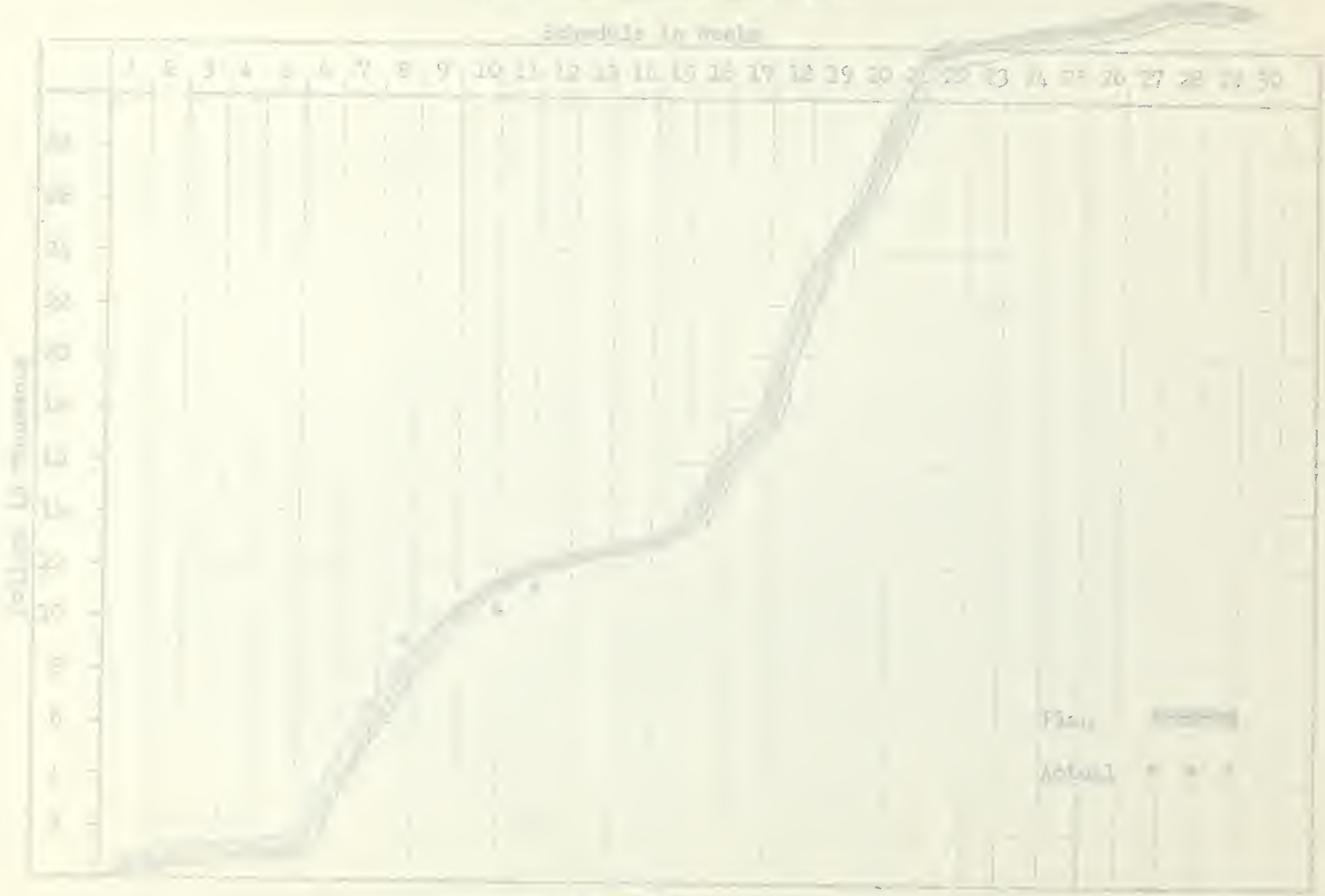

Figure 31.

J-1 PROJECT DIRECT COST STATUS

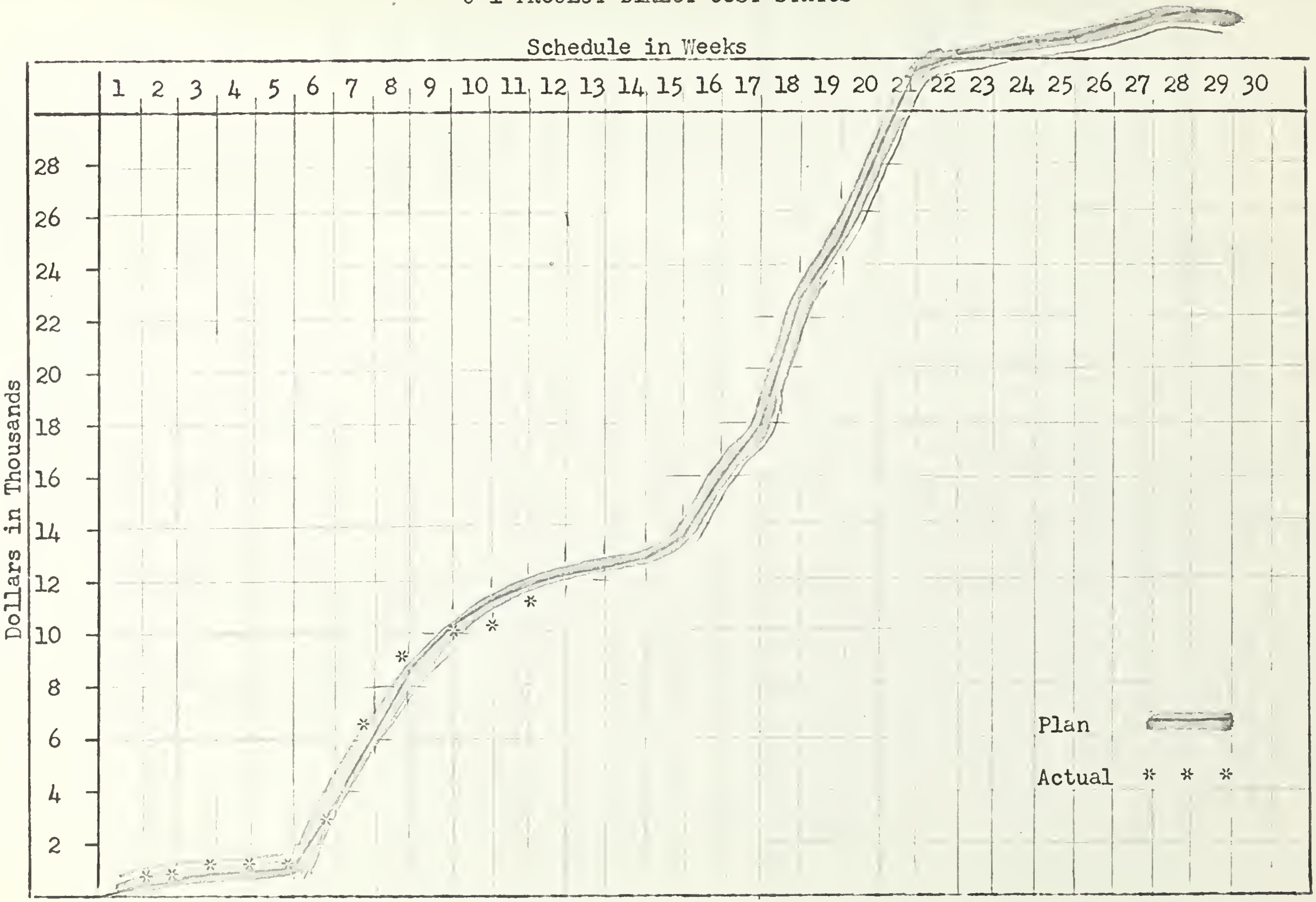

Figure 12.

date."[5] From this information the cost under-run or over-run to date can be determined. This variation together with schedule variation will permit a projection of a revised planned cost line. If the performance revealed by this time cost status information warrants a reestimate of cost-significant activities lying in the future, a projected line can be developed to include that date as well. With such data an explanation must be included of the basis for the variation and the forecasted additional variation, so that management can assess the significance of the variation and decide whether and how far to explore alternatives.

It can be seen from a review of the activities in the J-1 project that the schedule and cost estimating of some activities, such as 1221 Instrumentation Fabrication, cannot be performed to the highest degree of accuracy until other activities, such as the design work on 1212 Instrumentation Engineering, are completed. The DOD/NASA Guide states that it is preferable that the scheduling process be completed before firm cost estimates are made.[6] The sequential nature of the major subdivisions of the work breakdown structure is such that the early activities can be successfully costed and scheduled together[7], with detailed costing of the later activities delayed perhaps even until the early activities are actually started.

Having developed cost status information for trend indication, the effort required to estimate on a routine basis the work actually performed must be weighed against the usefulness to management of the variance revealed. The DOD NASA Guide, dealing with large, multi-contractor projects,

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[5] *PERT COST Systems Design*, p. 17.

[6] *Ibid.*, p. 51.

[7] *Ibid.*

suggests monthly reporting.[8] In projects of smaller scope than multi-year projects, monthly reporting may not suffice because the work breakdown approaches or goes below a month's span. Two alternatives seem to be available. One is to report the "contract price" as of activity completion dates, simplifying the task of estimating "contract" values. The other is to report contract price when the actual line deviates from the scheduled estimate line by a pre-selected dollar and or time amount. Both of these alternatives are identified as compromises to the full scale PERT/COST technique, which may be required because of the absence of ADP. Figure 13 illustrates in skeleton form the addition of original-estimate value of work actually performed to the cost status in Figure 12. Tabulations of costs on a project summary similar to the schedule summary illustrated in Figure 8 would serve top management in like manner.

The selection of data for inclusion in control reports is primarily a function of how quickly the data processing function can present it. Even though the capacity of a non-computer system is highly limited because of the requirement for timeliness, historical data in as much detail as the data collection system will allow must be collected: as activities and projects are completed the labor, material, dollar, and work center facts must eventually be tabulated in all of the arrangements useful for management planning. A reservoir of such historical information can be useful for preliminary cost and time estimation of future projects in advance of their formal assignment to the activity.[9]

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[8] _Ibid_. p. 135.

[9] _PERT Guide for Management Use_, p. 8.

P-3 CONTRACT COST PROGRESS CURVES

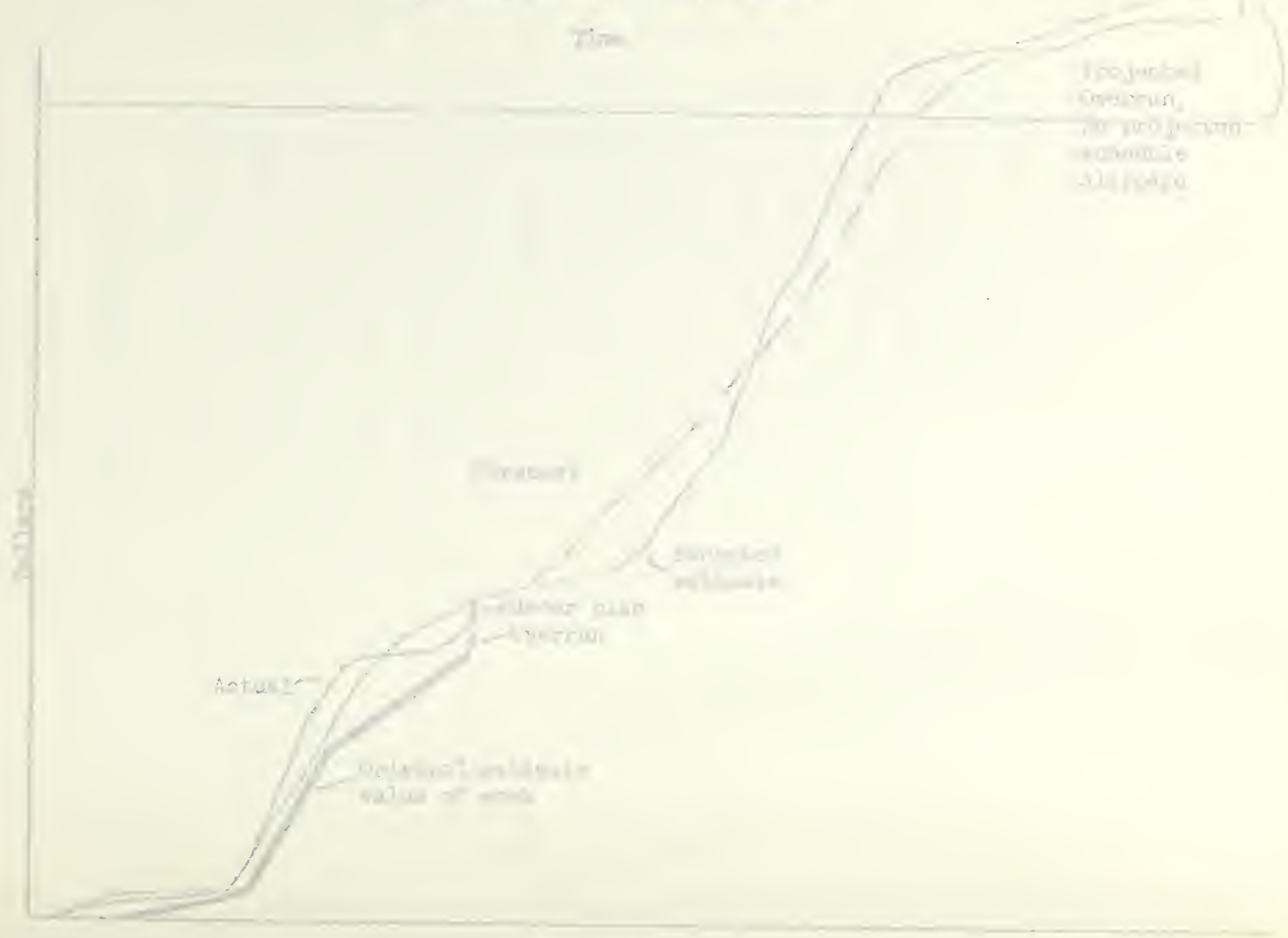

Figure 13

J-1 PROJECT COST PROGRESS REPORT

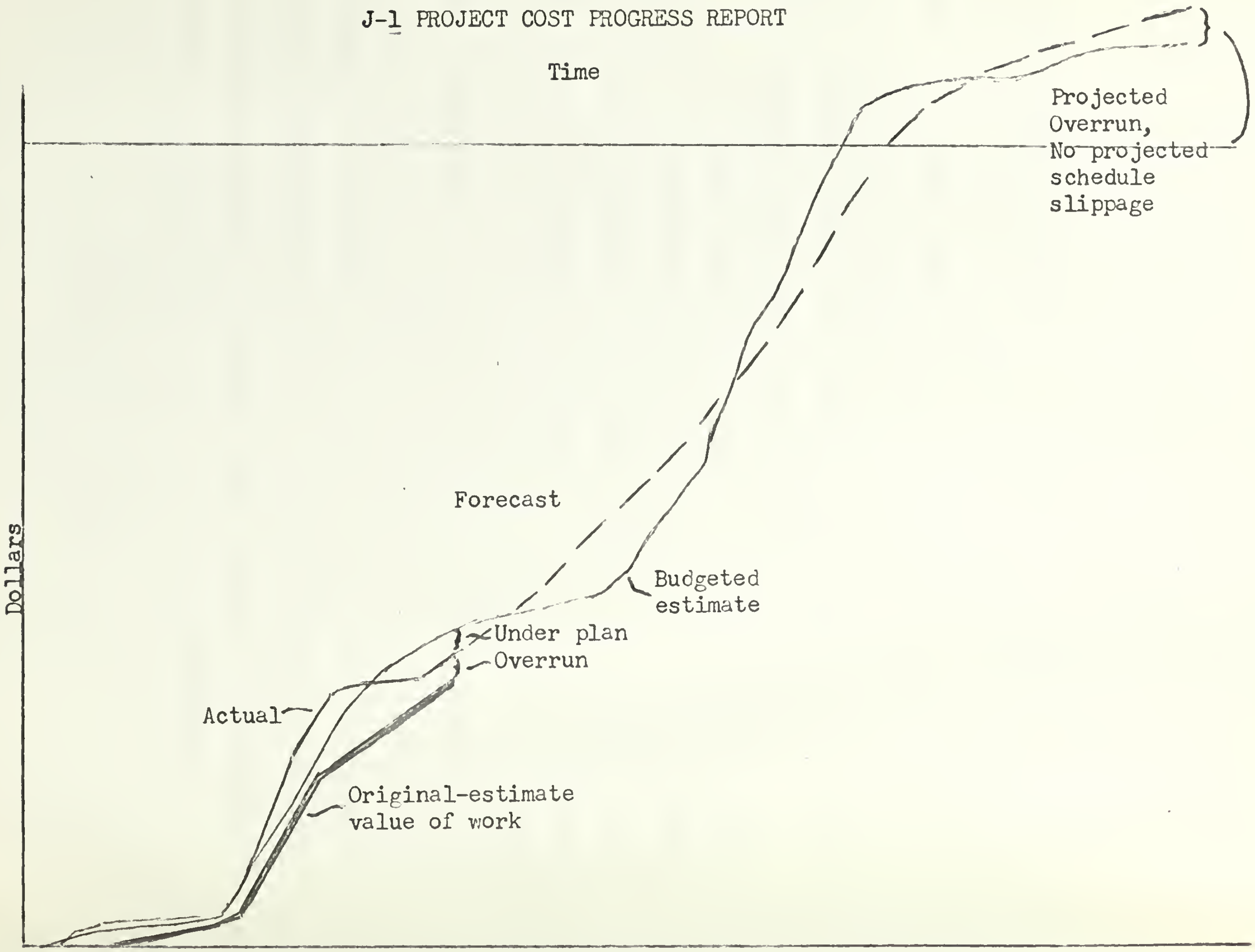

Figure 13.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Network systems are characterized by their highly organized approach to the planning function. Their usefulness is greatest in applications involving ill-defined work such as one-time or infrequently repeated projects, and complex programs such as major weapons systems and construction projects. They are based on the development of a model of the project which identifies the interrelationships and interdependencies of the individual tasks that make up the project; an evaluation of the network - and adjustment if necessary - in such a way that the risk of failing to reach the objective on time and within acceptable cost will be minimized, and the use of the network to monitor and control the project it represents. The newest of the rapidly developing network methods is the PERT technique.

The basic PERT method is time-oriented, and includes a means of determining the probability of achieving the schedule which it produces. This feature may be used where the uncertainties in the work being planned are high, or may be disregarded for more familiar tasks. The cost of accomplishing the project can be estimated in the network and can if necessary be related to the multiple time estimates of uncertain tasks to provide "most likely" costs of these tasks.

Evaluation of a PERT network identifies the "critical path" - that sequence of tasks called work packages or activities, which will, if delays occur in any one task on the path, delay the whole project. Knowledge of

this path, and of the amount of "slack" in the other paths through the network, enables management to devote its attention to the problems which arise that are potentially most serious in terms of jeopardizing the planned completion of the project, and to identify paths from which resources may be diverted or where work may be rescheduled to minimize deviations from the plan. When cost is applied to the network, an explicit assessment of the costs of alternatives is possible.

One of the requirements of PERT-type systems is that the breakdown of the projects into component tasks be continued until each work package can be identified to one organizational unit which will be responsible for its accomplishment. With the work breakdown structure identified to the organization structure, a system of control reporting is possible which relates to the tasks in the network and to the individuals responsible for each task.

In large, complex projects the number of activities in a network, and therefore the number of paths through the network, is large. Computing the time along these paths for identification of the critical path and the slack in the other paths, especially where significant uncertainty occurs in many of the activities, requires large volume of data processing. The same is true when evaluating alternative actions to minimize time or cost, or to replan parts of the network to relieve deviations from the original plan. Large amounts of data processing are also required to provide timely progress reporting in large projects. Therefore the PERT-type techniques as they are developing are oriented to automatic data processing.

Navy test and evaluation work is assigned to a wide variety of laboratories, stations, and units afloat. Any one activity, however, has a relatively narrow field of effort in terms of the kind of items it works with,

and the work it does tends to be repetitive in general outline. These two facts permit a certain degree of standard networking. "Prefabricated" networking of projects of relatively narrow scope reduces the amount of computation of critical paths, slack times and costs so that the work can be manually performed. Replanning will in the same way be reduced to a level susceptible to manual methods.

Progress reporting for control purposes must include actual performance against the plan, and a forecast. Schedule progress reporting summarizes upward the progress of each level of the work breakdown structure for the reporting period together with a forecast of the forthcoming period. In a non-automated system the level and amount of detail desired will have to be compromised with the capacity of the reporting system to deliver in a timely fashion. In this regard formality of the reporting system should not be allowed to reduce the volume and regularity of delivery of required information.

Cost reporting involves the reassembly of much of the cost information commonly collected under the Navy accounting system. The frequency of cost reporting and the detail required is largely a matter of judgement depending upon the size and complexity of the project and the significance of the activities in the work breakdown structure. Compromise solutions to the problem imposed by the limitations of a non-computer data processing function include reporting as of the end of selected time periods, or upon completion of selected activities in the network.

The extent of the use of PERT-type systems in test and evaluation projects in the absence of automatic data processing depends to a degree on the ability to develop standardized activities in a standardized network or a few standardized networks. This does involve a danger of so rigidly structuring a station's project work as to negate the value of the PERT

technique. To be useful a measure of flexibility must be retained to adapt to differences in projects and in project personnel.

The advantages of PERT systems lie their ability to systematize the planning of work, to reduce the chances of overlooking important contingencies, and to reveal the dependencies among the various work items that go to make up the project. Much of the benefit of networking lies in the improvement in planning. Success depends largely upon habituating the personnel taking part in the work to the use of the tool. For PERT techniques are essentially a way of looking at the work; they should not be regarded as mechanisms but as rational approaches to efficient and effective achievement of a project objective. That is to say, the applicability of PERT-type systems depends the ability of the users to approach the work in a certain fashion rather than upon the availability of sophisticated data handling systems.

It would be unrealistic to suggest that no test and evaluation activity in the Navy has adequate planning and controlling under their current system. Rather, it is concluded that network analysis can verify the validity of current planning and controlling techniques, and can provide a more effective technique if the current one is judged inadequate on the basis of past schedule and cost performance experience. The advantages of the network technique depends not upon the capacity of the data processing function but of its acceptability to managers. The hypothetical project not only illustrates the technique but demonstrates in a general way its feasibility within the limits selected.

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